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THE PALEOZOIC STRATIGRAPHY OF NEW YORK

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THE PALEOZOIC STRATIGRAPHY OF NEW YORK

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THE PALEOZOIC STRATIGRAPHY OF NEW YORK

Prepared under the direction of D. H. Newland

INTRODUCTION

By D. H. Newland

SCOPE AND PURPOSE OF EXCURSION

The excursion into the interior of New York State is intended mainly for students of stratigraphy and paleontology, but it will also provide opportunity to obtain a broad understanding of the geomorphology and glacial features along the route. The itinerary includes typical localities and sections of the Paleozoic within the area between the Adirondacks and the Pennsylvania State line and the region west to Lake Erie. This is the field wherein Hall, Vanuxem, Emmons, and other members of the original survey of New York (1836–1841) laid the foundations for the classification and nomenclature of the stratified formations from the Cambrian to the higher Devonian, and their work, with later revisions, has been adopted as standard in North American geology. The type localities of many of the stratigraphic units, general and specific, taken from this field are viewed on the trip.

The route is shown on Plate 1. From Albany, the starting point, it leads through the southern part of the State by way of the Helderberg Plateau and the Schoharie and Susquehanna Valleys to the Finger Lake region at Ithaca. In this part the Ordovician and Silurian beds of the Hudson Valley, the Helderbergian formations at the base of the Devonian, and the eastern representatives of the overlying Devonian are inspected. The Ithaca region affords many typical sections of the stratified series from the Hamilton to the Chemung and has much of interest in its glacial and geomorphic features. Watkins Glen, at the head of Seneca Lake, and Letchworth Park, on the upper Genesee River, notable for its sections of the Portage rocks, are visited on the way to Buffalo and Niagara Falls, which are at the west end of the route. The scenic attractions of Niagara Falls and Gorge are perhaps the main appeal to visitors who come to this region for the first time, but the stratigraphy, the

glacial and subsequent history of the region, and the industrial developments are also of exceptional interest.

The route back to Albany follows the shore line of glacial Lake Iroquois for some distance, then crosses the belt of Medina rocks to Rochester. Here is seen the gorge of the lower Genesee River, with its section of the early Silurian beds. Remarkable glacial features are displayed along the route leading east to Syracuse. The Salina beds, which inclose valuable salt and gypsum deposits, are encountered on this stretch. The Clinton beds are found in their full development between Syracuse and Utica, where a detour is made to Trenton Falls, one of the historic localities for New York geology. Thence the way leads down the Mohawk Valley, affording a section from the Potsdam to the Frankfort, with another detour north to Saratoga Springs, over the Adirondack pre-Cambrian formations for some distance, and into Albany.

GEOGRAPHY OF NEW YORK STATE

Area and boundaries.—New York has an area of 49,204 square miles (127,438 square kilometers), inclusive of 1,550 square miles (4,014 square kilometers) of inland waters but exclusive of the parts of Lakes Erie and Ontario that fall within its limits.

In shape roughly triangular, the State is 310 miles (499 kilometers) long from north to south, on the New England border, and 325 miles (523 kilometers) wide between the eastern boundary and the western extremity south of Lake Erie. About two-thirds of the boundary is defined by rivers, lakes, and the sea; the rest is unmarked by special topographic features. The mainland barely reaches the sea in the southeasternmost angle, yet by reason of the Hudson River estuary and the islands at the mouth there is a long stretch of deep-water frontage, providing the excellent harbors that have determined the location and development of the city of New York.

Commerce.—The State of New York occupies a commanding position with reference to transportation and commerce between the Atlantic coast and the interior of the United States, as well as between the Eastern States and the more populous sections of eastern Canada. The Hudson River, a tidewater stream as far north as Albany and Troy, with its largest tributary, the Mohawk, affords a short low-level thoroughfare across the Appalachian barrier to the Great Lakes and the West, and with its canal connection with Lake Champlain it gives access by similar easy gradient to the upper St. Lawrence region. These aboriginal trade routes are now developed by railroads, canals, and highways which carry a large share of the commerce between

the coast and the interior. On the south the Delaware and Susquehanna Rivers have well-graded valleys that lead to the plateau district of south-central New York. The principal industrial centers of the State are situated along these natural trade routes.

Topography.—The topography of New York is well diversified; five mountain groups are represented, of which two are wholly contained within the State. Of these the Adirondacks, on the north, covering about one-fifth of the total area, are for the most part a rugged wilderness, with individual peaks rising a mile or more above sea level (Mount Marcy, 5,344 feet or 1,629 meters). The Catskills, which present a mountainous appearance from the east as they fall away to the Hudson Valley, are a dissected, more elevated part of the southern plateau belt; their summits are a little over 4,000 feet (1,219 meters) above sea level. The other mountains are the Taconic Range, on the eastern border, extending into Connecticut and Massachusetts; the Shawangunk (shon′gum) Mountains, folded ridges of the Appalachians that reach into southeastern New York from Pennsylvania; and the Highlands, a part of the frontal crystalline range of the Appalachians, which continues southwestward into New Jersey and Pennsylvania and northeastward into New England.

The Adirondacks, physiographically an independent mountain group, are composed of pre-Cambrian crystalline formations, closely related to the rocks of the Grenville subprovince of the Canadian shield, of which the Adirondacks may be regarded in a geologic sense as a southern outlier. Much of their area is included in the State Forest Preserve, which is likewise a game refuge, and the whole region is a popular resort for health seekers and tourists. The region contains valuable deposits of iron ore, zinc, pyrite, talc, graphite, and garnet, as well as a variety of building stones.

The Great Lakes-St. Lawrence system takes the run-off of about one-half of the total area of the State, carried by numerous short streams, none of them navigable. The drainage is interrupted by many lakes, such as the scenic Finger Lakes in the central part and hundreds of smaller lakes in the Adirondack region. The glacial invasion produced most of the lakes through blocking or overdeepening of the stream channels. The Hudson-Mohawk drainage system receives most of the run-off from the eastern part of the State, with the exception of the southeastern area, which drains into the Susquehanna and the Delaware. The Allegheny drainage basin, in the southwest corner, is tributary to the Ohio and the Mississippi.

Water power.—Water power is an important natural resource of New York. The development in 1930 amounted to 1,805,195

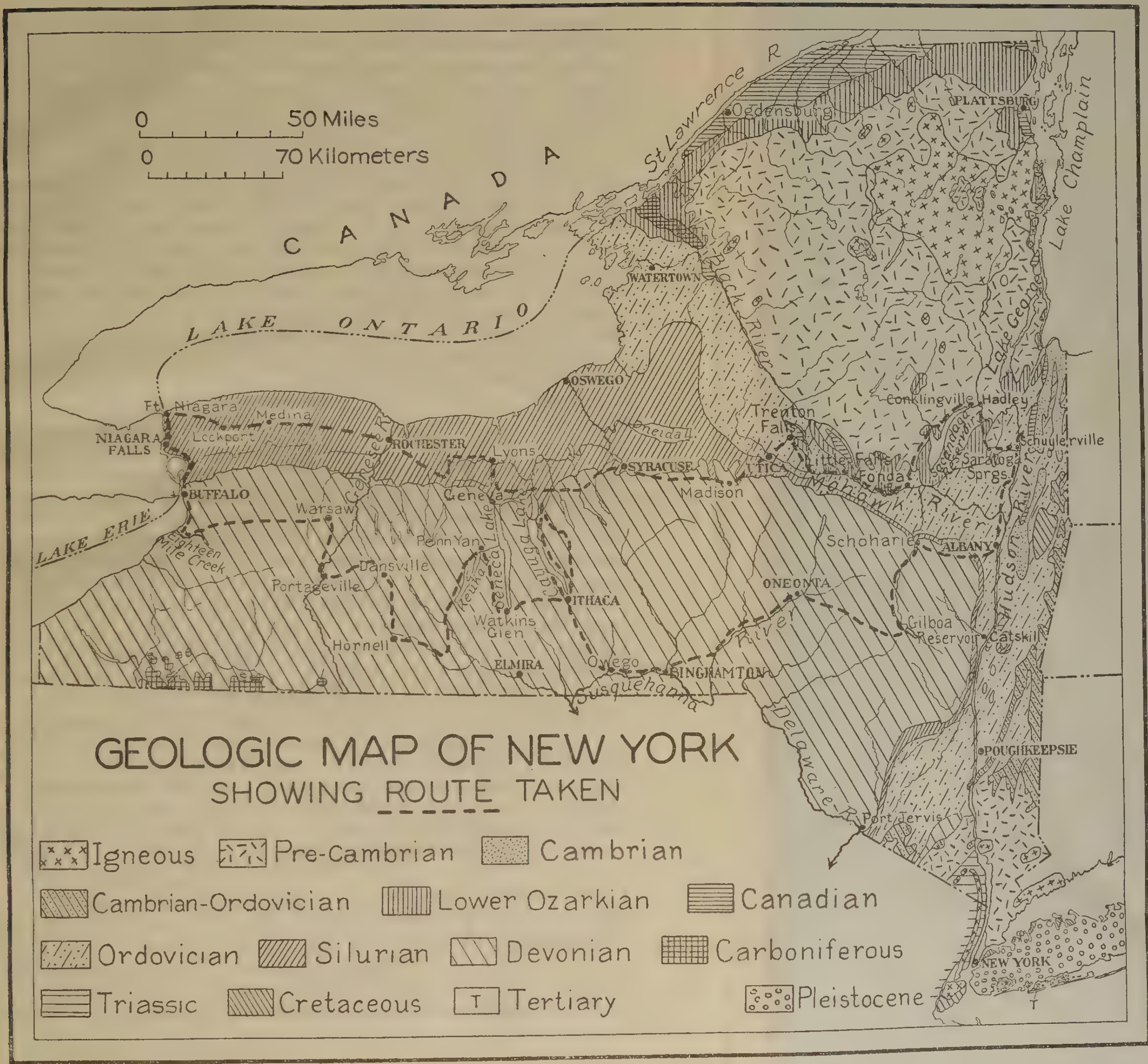
horsepower, or 13 per cent of the total for the United States. The potential power available for 90 per cent of the time is estimated at 3,940,000 horsepower. The Niagara-St. Lawrence power facilities are shared, of course, by Canada, as the international boundary follows the middle of those rivers.

Climate.—The range of temperature between summer and winter is fairly high, especially in the interior, where the climate is in some degree continental in character. The minimum winter temperatures are reached in the Adirondacks (−35° to −45° C.); the maximum summer heat is felt in the interior lowlands and the lower Hudson Valley (35° to 38° C.). The prevailing winds blow from the west, and the passage of successive high and low pressure areas across the State brings an alternation of clear, dry weather with cloudy, rainy weather. The annual rainfall ranges from 30 inches (762 millimeters) in the central part to 60 inches (1,524 millimeters) on the coast and on the west side of the Adirondacks, which receives the moist winds from the Great Lakes. It is well distributed over the seasons, so that droughts are rare.

Flora and fauna.—The country was an almost unbroken forest when it was first entered by whites. The lands cultivated by the Indians were confined to small tracts of lowland along the rivers and lakes. Remnants of the primeval forest are still preserved in the Adirondacks, Catskills, and southern plateau region. The Adirondack summits carry a subalpine flora, but elsewhere the forms are those common to the adjacent States and to Canada. About 1,500 species of flowering plants have been enumerated, and the average township has from 500 to 800 species. Of ferns and allied forms there are 92 species. The trees number 125 species, of which over 100 are hardwoods, inclusive of oak (16), hickory (6), birch (6), maple (5), willow (19), thornapple (35), elm, ash, walnut, chestnut, birch, and basswood. There are 22 species of softwoods, inclusive of pine (6), spruce (3), larch, hemlock, cedar, and balsam.

The native animal life has been reduced greatly in numbers and range, particularly for the larger land forms, within the last century or more. The elk, moose, caribou, puma, wolverine, and wolf have been exterminated. Beaver, after suffering extinction, have been reintroduced in the Adirondacks and Catskills and are now fairly common on some streams. Deer (northern species of the Virginia deer) are plentiful in the forested regions, and the black bear is an occasional resident. Bird life abounds, as most species are under State protection.

History of settlement.—The Iroquois tribes, known as the Five Nations (later joined by the Tuscaroras to make the Six Nations) were the dominant power in New York when it was first entered



GEOLOGIC MAP OF NEW YORK
SHOWING ROUTE TAKEN

by white settlers. They were more sedentary than nomadic, living in bark huts, often built in groups and surrounded by stockades, and dependent to a considerable extent upon farming for their food supplies. Maize, or Indian corn, popularly known as corn, was the chief crop. Their principal seats, or castles, were in the Mohawk Valley, the Finger Lake region, and the shores of Lakes Erie and Ontario. They maintained almost constant hostilities with the Algonquins and Hurons, who lived to the north and west. The Mohawks, the eastern tribe, and the Senecas, the western branch of the "Long House," or Iroquois Confederacy, bore the brunt of this warfare.

Samuel de Champlain and Henry Hudson were the first to explore any part of the interior of New York State and curiously enough entered it in the same year, 1609, from opposite points. Champlain from a base on the St. Lawrence explored the lake which bears his name as far as Ticonderoga, where he came into contact with the Iroquois. Hudson discovered New York Bay and sailed up the river to about the site of Albany. Hudson's voyage, undertaken for the Dutch East India Co., was followed almost immediately by the development of a prosperous fur trade and the settlement of New Amsterdam (New York) and Fort Orange (Albany) as posts for the merchants engaged in the business. French missionaries and traders from the St. Lawrence River towns explored the interior of the State in the middle of the sixteenth century but made no permanent settlements.

Until after the Revolution white occupancy was limited almost wholly to the coast and the Hudson and Mohawk Valleys. The settlement of the interior did not progress rapidly until after the beginning of the nineteenth century, the pioneers coming mostly from New England. Later followed a large immigration from Germany, the Netherlands, and the British Isles.

Population.—The census of 1930 gives the population of the State as 12,588,066, which is slightly more than 10 per cent of the total for the United States. The first census (1790) showed a population of 340,120. The present average density is about 264 to the square mile (102 to the square kilometer). A little more than one-half of the population (6,930,446) is in New York City. The State has 10 Indian reservations with nearly 5,000 inhabitants.

Industries.—Manufacturing, commerce, and finance are the leading activities. The list of manufactured products extends to nearly all items of present-day industry. The value of the manufactures in 1927 was $9,400,061,376.

The port of New York leads all other ports of the United States in foreign trade; its commerce amounts to about one-half

of the total value of imports and exports each year. The city is also the leading financial center of the country.

Agriculture and mining contribute materially to the general welfare, though subordinate in output to manufacturing. The mineral output consists of iron and zinc ores, pyrite, salt, gypsum, talc, cement, building stones, and clay materials, as well as a number of minor products, in all having an annual value of over $100,000,000. Dairying, small farming, and fruit growing are the chief agricultural occupations. One-half or more of the total area is in farms.

GEOLOGY OF NEW YORK STATE

New York State shares many of the formational and structural features that characterize the geology of eastern North America. The rock succession spans the entire stratigraphic column, with representatives of all the common kinds and types of sedimentation, a variety of glacial deposits, and many of the plutonic and dike rocks to be found in the region. The periods of widespread mountain uplift and metamorphism—pre-Cambrian, Taconic, and Appalachian—find their local record, as likewise the main periods of base-leveling and submergence.

The stratigraphic succession has for its base the pre-Cambrian complex of sediments and igneous rocks which constitutes the fundamental series of the continent. These formations crop out over about a quarter of the State and compose the basement on which rests the stratified series in the remaining area.

Above the pre-Cambrian, separated by a structural and erosional unconformity that implies a very long time interval, is the Paleozoic succession, consisting in the main of little-disturbed fossiliferous beds. They have an aggregate thickness in the local sections of over 4 miles (6.4 kilometers). They carry the record from the Cambrian to the base of the Pennsylvanian or Coal Measures, with little interruption to the sequence. They occupy considerably more than half of the State.

An interval that extends across the major part of the Pennsylvanian and the whole of the Permian is unrepresented, but the Mesozoic succession appears in southeastern New York in the Newark formation (upper Triassic) of sandstone, shale, and intercalated trap sheets and also in a thin series of Cretaceous beds within the Coastal Plain. All of the interior portion of the State was a land area throughout the Mesozoic era and by the end of Cretaceous time had reached the condition of a more or less perfect peneplain (Kittatinny), still well preserved in the Catskills and the Taconic-Green Mountain range.

Geologic section for New York State

System	Series	Stage or formation [a]
Quaternary.	Recent.	
	Pleistocene.	Wisconsin.
Tertiary.	Not differentiated.	
Cretaceous.	Upper Cretaceous.	Representatives of parts of Monmouth, Matawan, Magothy, Raritan, and Cliffwood formations.
Triassic.	Upper Triassic.	Newark beds, with trap sills.
Pennsylvanian. (Upper Carboniferous.)	Pottsvillian.	Sharon shale. Olean conglomerate.
Mississippian. (Lower Carboniferous.)	Bradfordian.	Knapp beds. Oswayo beds.[b] Cattaraugus beds (including Kilbuck, Salamanca, and Wolf Creek (Panama) conglomerates).
Devonian.	Chautauquan.	Chemung beds (Catskill, eastern facies):[c] Wellsburg sandstone. Cayuta shale.
	Senecan.	Portage beds (Oneonta, eastern facies): Naples beds to west, including Wiscoy, Nunda, Gardeau, Grimes, Hatch, Rhinestreet, Cashaqua (including Parrish limestone), West River shales and sandstones, and Genundewa limestone. Ithaca beds to east, including Enfield and Ithaca shales and Sherburne sandstone. Genesee black shale. Tully limestone.
	Erian.	Hamilton beds: Moscow, Ludlowville (including Tichenor limestone). Skaneateles and Marcellus shales.
	Ulsterian.	Onondaga limestone. Schoharie grit.
	Oriskanian.	Esopus grit. Oriskany sandstone.
	Helderbergian.	Port Ewen limestone. Alsen limestone. Becraft limestone. New Scotland limestone. Kalkberg limestone. Coeymans limestone.
Silurian.	Cayugan.	Manlius limestone. Rondout waterlime. Cobleskill (Akron) dolomite. Salina beds: Bertie water lime, Camillus (Brayman?), Vernon, and Pittsford shales.
	Niagaran.	Guelph dolomite: Upper Shelby. Lower Shelby. Lockport dolomite, including Gasport limestone near base. Clinton beds: Rochester shale, Irondequoit limestone, Williamson shale, Wolcott limestone, Sodus shale, Reynales limestone, Furnaceville iron ore, Brewer Dock beds, Maplewood shales, Thorold sandstone (Oneida conglomerate).
	Medinan.	Albion: Grimsby sandstone. Cabot Head shale. Manitoulin beds. Whirlpool sandstone. Queenston shale.
Ordovician. (Ulrich restricted, 1911.)	Cincinnatian.	Oswego sandstone. Lorraine beds: Pulaski shale. Frankfort shale. Utica shale.
	Mohawkian.	Trenton beds: Schenectady shale, Trenton limestone (Canajoharie shale equivalent, with Snake Hill of same age farther east). Black River beds: Amsterdam, Watertown, Leray and Lowville limestones.
	Chazyan.	Chazy limestones (Normanskill shale of Chazy age and younger in east, including Rysedorph conglomerate at top).
Canadian. (Ulrich, 1911.)	Canadian with Chazyan=Lower Ordovician of authors.	Beekmantown limestone (Deepkill shale of same age in east). Tribes Hill limestone. Schaghticoke shale (farther east).
Ozarkian. (Ulrich, 1911.)	Ozarkian (Saratogan)=Uppermost Cambrian of authors	Little Falls dolomite. Hoyt limestone. Theresa formation. Potsdam sandstone.
Cambrian.	Acadian.	Stissing limestone.
	Taconian. (Georgian.)	Georgia beds: Bomoseen grit, Schodack shales, Nassau beds, Troy shales. Poughquag quartzite.
Pre-Cambrian.	Keweenawan.	Late pre-Cambrian trap dikes.
	Algoman.	Anorthosite-syenite-granite complex.
	Laurentian.	Early pre-Cambrian intrusions.
	Grenville.	Great series of metamorphosed sediments; sequence not fully determined.

[a] Subdivisions are named from top downward.
[b] Recent studies of K. E. Caster indicate that the base of the Mississippian should be drawn at the base of the Oswayo beds.
[c] This name has been widely extended over red beds locally topping the Devonian and now known to be of progressively later age from east to west. The type area in the Catskill Mountain front, at the east, is not younger than Portage in age, whereas the most westerly beds are in the highest Bradfordian.

The Tertiary has a moderate representation in the coastal region, where deposits of that period rest unconformably upon the Cretaceous beds. The interior was a land surface undergoing erosion in Tertiary time. Pleistocene morainal and lake deposits are spread over most of the surface of the State.

The stratigraphic sequence for New York shown in the accompanying table follows the contemporary classification used by the State Geological Survey, which differs in many details from that employed by the United States Geological Survey.

STRATIGRAPHY

Pre-Cambrian.—The lowest formations of the pre-Cambrian, exposed in the Adirondacks and southeastern Highlands, are those of the Grenville series, represented by crystalline limestone, quartzite, and various banded gneisses. The name is taken from the Grenville region of eastern Ontario. The formations are regarded as equivalent to the oldest of the Lake Superior formations, but this view is not unquestioned. Their wide distribution—although present outcrops are confined to remnant patches and belts—suggests that the sediments once occupied much or all of the Adirondack region, as well as outlying areas now covered by Paleozoic beds; and they were developed on a considerable scale in southeastern New York. The sequence and structure of the beds offer difficult problems to the geologist. They have been invaded and more or less assimilated by igneous magmas and show the effects of both contact and regional metamorphism. In the Adirondacks they attain a thickness of 2 to 3 miles (3.2 to 4.8 kilometers), and as nearly as can be estimated one-half of the total is limestone.

Deep-seated igneous rocks occupy most of the present surface of the Adirondacks. According to prevalent opinion they represent two periods of intrusion, both post-Grenville, the earlier regarded as Laurentian and the later as Algoman. The earlier series consists of metagranite and metagabbro in rather small outcrops. The Algoman members are the predominant Adirondack formations and constitute a closely related group, the differentiated fractions, probably, of a single parent magma. They include anorthosite, gabbro, syenite, and as the acid phase granite and granite pegmatite. The anorthosite crops out as a body of nearly 1,200 square miles (3,108 square kilometers), situated a little east and north of the center of the region. It is surrounded by the other members in many large and small individual areas. The differentiation of the magma, whether it took place in the depths of the earth before intrusion or later and near the surface in a great sheet or laccolith, has engaged much

attention; and the relationship of the different members and their sequence are interesting problems not fully solved.[1]

In the Highlands the igneous masses are mostly granite, believed to be Algoman.

Of late pre-Cambrian formations the only representatives are igneous; basic dikes, largely diabase, occur in numbers in the northern and eastern Adirondacks and are not wanting in the other parts of that region and in the Highlands. Their age can not be more closely stated than that they are earlier than the period of erosion that preceded the Potsdam marine invasion and are later than the last of the plutonic intrusions. Their correlation with the Keweenawan volcanic rocks of Lake Superior is somewhat tentative.

Iron ores, mainly magnetite, are present in the pre-Cambrian of the Adirondacks and the Highlands region and have been extensively mined. Their origin is connected with the igneous intrusions of the Algoman series; bodies of mixed ilmenite and magnetite are found in the anorthosites and gabbros; but in the syenites, granites, and assimilated Grenville rocks of higher silica content the ores carry only small amounts of titanium. Zinc ore (sphalerite), pyrite, and hematite occur as replacement deposits in the Adirondack Grenville. Talc, graphite, and garnet are of economic importance in the nonmetallic group.

Cambrian.—The Cambrian system, as here defined, is represented by the Georgia slates in the highly folded region east of the Hudson River and possibly by the Stissing limestone in the same region. The Georgia beds carry the *Olenellus* fauna and are therefore Lower Cambrian. The presence of the Stissing limestone in the vicinity of Stissing Mountain, Dutchess County, in the southeastern part of the State, has been explained by thrust faulting from the Taconic region to the east. In Cambrian time New York State seems to have been mostly land undergoing erosion; strata of this age are absent from the whole area west of the Hudson-Champlain Valley.

Ozarkian.—The New York Ozarkian section is the Lower Ozarkian of Ulrich,[2] the Upper Cambrian of the older classification. The Potsdam formation, a hard sandstone or quartzite, represents the first widespread Paleozoic sedimentation within the State; deposition began in the Champlain trough and pro-

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[1] Bowen, N. L., The problem of the anorthosite: Jour. Geology, vol. 25, pp. 209–243, 1917. Balk, Robert, Structural geology of the Adirondack anorthosite: Min. pet. Mitt., Band 41, pp. 308–432, 1931. Buddington, A. F., Granite phacoliths and their contact zones in the northwest Adirondacks: New York State Mus. Bull. 281, pp. 51–107, 1929.

[2] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pp. 281–680, 1911.

gressed southward, northward, and westward around three sides of the Adirondack region, which had previously been base-leveled. The beds still preserve a nearly horizontal position, overlapping on the pre-Cambrian. They grade upward by a succession of alternating sandstone and sandy limestone layers (Theresa beds) into the Little Falls dolomite (Calciferous sandstone of early authors), which is well represented in the Mohawk Valley. The Hoyt limestone is a rather local facies on the southern border of the Adirondacks. The Ozarkian has an aggregate thickness in New York State of 1,800 feet (549 meters).

Canadian.—The Tribes Hill and Beekmantown limestones, formerly placed with the Chazy at the bottom of the Ordovician, are here given separate rank as the Canadian system. The Tribes Hill fucoid layers are found in the Mohawk Valley, resting upon Little Falls dolomite. After their deposition the Beekmantown began to accumulate in the Champlain trough and in the Ogdensburg area, on the northwest side of the Adirondacks. The Canadian system includes over 1,800 feet (549 meters) of beds.

Ordovician.—The marine invasion in northern New York reached its maximum spread, with the submergence of all but the central Adirondacks, during the Ordovician period. At the start sedimentation was restricted mainly to the Champlain trough, where the Chazy, a highly fossiliferous limestone, was laid down. With the deposition of the Mohawkian series, represented by the Black River (including Lowville) and Trenton beds, submergence progressed until probably nearly all of the State was covered and received shaly and limy sediments. In the Mohawkian series the shaly members are predominant in eastern New York, but to the west limestone is a conspicuous element. The Cincinnatian, or Upper Ordovician, represents a shallowing of the seas, with shale (Utica, Frankfort, Pulaski) and sandstone (Oswego) as principal materials, restricted to the southwest side of the Adirondacks and to the south of the east end of Lake Ontario. The full section of the Ordovician, a composite of different local measurements, is over 5,000 feet (1,524 meters).

Silurian.—The base of the Silurian system is here held to be the Medinan, consisting of some 1,200 feet (366 meters) of shales and sandstones, which crop out in a belt averaging about 10 miles (16 kilometers) wide along the south shore of Lake Ontario. The lower beds in western New York are designated the Queenston shale, above which are white sandstones, then red shales and gray sandstones to the top. The formation is persistent south of the outcrop under cover of the higher beds and seems to have been a delta formation in the Appalachian

trough, occurring as far south as Virginia. The sandstones of the upper horizon are prolific sources of natural gas in western New York.

The Oneida conglomerate, a local formation confined to the central part of the State, is here placed in the Niagaran series and considered as representing the initial stage of the Clinton submergence, as likewise is the Shawangunk conglomerate of southeastern New York. Niagaran time was marked by a general marine invasion throughout the region south of the Adirondacks to the Taconic uplift on the east. The Clinton beds, which have their type locality near Utica, are represented in many of the States south of New York and throughout their extent are in many places, though not everywhere, characterized by the presence of one or more layers of fossiliferous hematite. They were probably laid down in shallow waters and lagoons, but the waters deepened and cleared in the Lockport stage, which is represented by a reef formation of dolomite.

In Cayugan (late Silurian) time Salina deposition took place largely in the form of chemical precipitates—rock salt, anhydrite, and dolomite—indicative of arid conditions and waters shut off from the open sea. The Salina basin extended over a large area beyond the limits of the State; the contained salt and gypsum deposits are the largest in the East. The anhydrite beds pass into gypsum only within a zone extending a few hundred feet below the surface where surface waters have reached them. One-third or more of the full section of 1,200 feet (366 meters) of the New York Salina consists of rock salt. At the end of the Salina epoch, with freshening of the waters, water limes (Bertie) carrying a remarkable eurypterid fauna were deposited. Normal marine conditions were restored with the spreading of the seas in the Appalachian trough during the remainder of the Cayugan, when the Cobleskill, Rondout, and Manlius beds were deposited.

Altogether the Silurian strata have a thickness of 2,600 to 3,000 feet (792 to 914 meters) in central New York.

Devonian.—The Devonian period began without notable change of conditions from those at the end of the Silurian. Devonian strata cover more than one-third of the State and no doubt formerly extended considerably beyond their present limits to the east and north. In the lowermost division, the Helderbergian, limestones predominate and include the Coeymans (Lower *Pentamerus*), New Scotland, Becraft (Upper *Pentamerus*), and Port Ewen members. They are developed in the Catskill-Helderberg region of eastern New York.

The Oriskany sandstone represents a period of marine transgression that followed an interval of uplift and erosion at the

end of Helderbergian time. The beds crop out in broken succession east and west across the State. In southeastern New York the Esopus grit seems to be a delta deposit in a succeeding interval after uplift in the Appalachian trough.

The Schoharie grit, found only in eastern New York, marks the start of the widespread submergence of the Middle Devonian that led to the deposition of the Onondaga limestone, which by its wealth of corals and brachiopods seems to indicate warm, clear seas. It is one of the most persistent and uniform of the local formations; the outcrop extends from the Niagara River east to the Hudson Valley near Albany and thence south and southwest beyond the Pennsylvania boundary. Elevation of the land in the east brought a rejuvenation of the streams at the end of Onondaga time, checking the formation of limestone.

The Hamilton-Marcellus (Erian) formation introduces the great succession of shales and flags which were laid down during the remainder of the Devonian period, excepting for one or two brief intervals of limestone deposition. These shales attain a thickness of 1,600 feet (488 meters) in eastern New York but thin to the west, away from the source of the sediments. At the end of Hamilton time came an interval of uplift and erosion, and then again submergence with accumulation of detrital deposits over western New York.

The Genesee beds lie at the base of the Upper Devonian in central and western New York—except in the Finger Lake region, where a thin layer of limestone (Tully) is at the bottom—and consist of black bituminous shale, 100 feet (30 meters) or less thick. The succeeding Portage beds, 1,500 feet (457 meters) in maximum thickness, are more sandy, with abundant flags. They carry the Naples fauna in western New York but farther east are replaced by the Ithaca formation, of Hamilton faunal aspect. In the extreme east the nonmarine Oneonta beds, 2,000 to 3,000 feet (610 to 914 meters) thick, represent the uppermost Portage.

The Chemung, a marine formation in western New York, where it holds oil and gas pools, is succeeded to the east by the Catskill fluviatile and estuarine deposits. From these and from the Portage series is obtained much of the fine-grained sandstone (bluestone) quarried in the State. About 1,500 feet (457 meters) of sediments are assigned to the Chemung; the Catskill beds reach a thickness of 3,000 feet (914 meters). The total Devonian section in New York State has a thickness of 8,000 to 9,000 feet (2,438 to 2,743 meters).

By the end of the Devonian period the greater part of the State had emerged above sea level; beds of Carboniferous age are found only in the extreme southwestern part, on the Penn-

sylvania border. The Lower Carboniferous, or Mississippian system, is represented by a few hundred feet of sandstone and conglomerate in Cattaraugus and Allegany Counties—the remnants, perhaps, of a considerably larger area of accumulation. Of the Pennsylvanian system (Coal Measures) only the Olean conglomerate and the Sharon shale are to be found, within small outcrops. These are the highest of the Paleozoic beds in New York, as the Permian is wholly missing.

Triassic.—The Mesozoic stratigraphic column is much abbreviated in New York State, with the principal development comprised in the Newark beds, of Triassic age. The beds are made up of sandstones and shales, found only in Rockland and Richmond Counties, on the New Jersey border. Intrusions of diabase occur along the bedding planes of the sediments, and the eastern margin of one of these sill-like intrusions, characterized by columnar jointing, forms the Palisades of the lower Hudson River.

Cretaceous.—Clays and sands, little consolidated and carrying Cretaceous plant remains, occur in the Coastal Plain province, which in New York State is restricted to Long Island and Staten Island.

Quaternary.—Pleistocene glacial deposits are found over all of the State in such forms as till, drumlins, kames, outwash deposits, and modified drift or lake deposits. The occurrence of more than one period of ice advance seems probable in view of the evidences found elsewhere, but it has not been substantiated by the discovery of interglacial deposits—of any wide extent, at least—in New York. The deposits are generally assigned to the Wisconsin stage of the late Pleistocene epoch.

STRUCTURE

Orogenic folding and faulting are confined to a few distinct regions within the State—the Adirondacks, the southeastern Highlands, and the Taconic region east of the Hudson River. For the rest of the State, including in general all the areas north of the Highlands and the Pennsylvania border to the Mohawk River and Lake Ontario, the rock formations have been uplifted to their present positions for the most part without much differential movement.

Adirondacks.—The surface geology and structure of the Adirondack region are complex and not yet fully known. The key to the present arrangement of the pre-Cambrian rocks lies largely in the interpretation of the structural features of the Grenville series, which includes the only sediments antecedent to the Paleozoic strata. The Grenville beds show the effects of great compression and are tilted and in places folded into intricate

patterns. Folds in the northwestern sector have been found to be isoclinal in zones of extreme pressure. The axes trend generally northeast; the same trend characterizes the arrangement of the ridges and mountains where the Grenville is much in evidence.

Over extensive areas the Grenville formations occur only in meager outcrops, surrounded and bottomed by the igneous bodies. This is the condition over much of the central and northern Adirondacks, particularly in the area covered by anorthosite. There the mountains follow no particular pattern or trend.

The more recent studies indicate that the magmas of the main Adirondack series conformed in their intrusions to the Grenville structure, rather than that they broke indiscriminately across the Grenville as stocks or batholiths, lifting or shouldering aside the beds. The final differentiation may have occurred near the outer zone rather than in the interior. The anorthosite body is perhaps a great laccolith or convex sheet bottomed by Grenville. It has been shown conclusively by Buddington[3] that many of the later granite intrusions are sills or lenses intruded concordantly on the wings of folds, or disks that occupy the summits of compressed anticlines, and probably were intruded contemporaneously with the deformation. The older (Laurentian) intrusions seem to have preceded the principal stage of folding.

On the east side the Adirondacks descend abruptly to the Champlain trough, the result of meridional faults that drop the Paleozoic beds along the west margin of the lake. Lake George occupies a faulted block in continuation of these dislocations. On the south the pre-Cambrian area is notched by a series of northeasterly faults which have their downthrow to the southeast. The rest of the border generally is unmarked by displacements, and the pre-Cambrian surface disappears beneath the Paleozoic without notable structural features other than that of unconformity. The ring of Paleozoic beds where unfaulted shows an outward dip, away from the Adirondack highland.

Southeastern Highlands.—The ridges that cross the Hudson River in the gorge section between Cornwall and Peekskill consist of pre-Cambrian granite, diorite, and gneiss; small bands of crystalline limestone and schist occur in the valleys. The formations are broadly comparable to those of the Adirondacks; the limestone and schist are the local phase of the Grenville series, and the igneous rocks probably belong to the early pre-Cambrian (Algoman?). The intrusion of the igneous rocks may

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[3] Op. cit.

have been an accompaniment of folding; the Grenville is upturned and runs in belts parallel to the structural trend.

On the north side the Highlands are bounded by a great fault, a thrust fault in part, which terminates the crystalline rocks abruptly against the Cambro-Ordovician terrane. Parallel northeast faults are shown elsewhere in rock scarps and deep valleys; the Peekskill-Tompkins Cove fault in its southwesterly continuation divides the pre-Cambrian from the Triassic of the Palisades region west of the Hudson River.

Taconic region.—The Taconic disturbance (post-Ordovician) is revealed most clearly in the sedimentary terrane to the east of the Hudson-Champlain Valley. The region, largely underlain by shales and limestones of Cambrian and Ordovician age, is broken by a series of north-northeast folded ridges of which the northern continuation is the Green Mountains. The beds show progressive metamorphism from the Hudson Valley eastward; on the New England border they are represented by slates, phyllites, and marbles; close to the Hudson they consist for the most part of shales and fossiliferous limestones. The Silurian formations rest horizontally upon the upturned Ordovician.

A prominent structural and physiographic feature is the thrust faulting, by which the position of beds may be reversed over long stretches. Thus Cambrian sediments are shoved over the Ordovician in low-angle movements that take place usually from east to west. One such series of overthrusts, which extends in more or less interrupted sequence from the St. Lawrence River south through Vermont and into New York, is known as Logan's line, after Sir William Logan, who first recognized its wide structural importance.

Interior of the State.—The plateau that occupies most of the interior is formed by Devonian strata slightly tilted toward the south. It is an uplifted coastal plain, shelving slightly away from the Adirondack and Canadian highlands that defined the old shore line. The plateau averages about 2,000 feet (610 meters) in altitude on the Pennsylvania border but is downwarped in the region of the Finger Lakes, the bottoms of whose north-south basins, overdeepened by glacial erosion, may even reach sea level. The normal southerly dip of the formations is interrupted in that area by low cross folds, the last effects of the Appalachian folding to the west.

The surface falls away gradually on the north to the level of the Lake Ontario plain, 500 feet (152 meters) or less above sea level, and more abruptly on the east to the broad, deep Mohawk Valley. The outcrop of the harder limestone formations is shown in a series of parallel east-west escarpments—for example, the Helderberg escarpment, in the east, and the Niagara and

Onondaga escarpments, in the western and central parts. Thick shale beds, particularly the Medina and Salina shales, account for the smooth contour of the Lake Ontario plain.

GEOLOGIC HISTORY

Pre-Cambrian time.—The local record of events in pre-Cambrian time, so far as at present known, includes in general sequence (1) a period of submergence and accumulation of sediments; (2) uplift of the beds with deformation and igneous invasions in two principal series; (3) long subsequent weathering and erosion, which reduced the mountainous surface to a low level; (4) late pre-Cambrian igneous activity of minor scope: (5) continuance of the erosion cycle leading to a peneplaned condition of the whole pre-Cambrian area, followed by a general downwarping and encroachment of the sea from the east.

1. The oldest formations, those of the Grenville series, are marine deposits consisting of materials that must have been thoroughly broken down, disintegrated, and sorted before deposition. Limestone, both calcareous and dolomitic, is the most abundant element of the beds, but whether it represents organic or chemical deposition is not determinable in the absence of fossils. The Grenville sea occupied a much larger area than is indicated by the present outcrops of the sediments in the Adirondacks and southeastern Highlands, undoubtedly spreading south and west over the area later planed off and covered by the Paleozoic formations. The basement of the series has not been recognized. Grenville time must have been very long, even with allowance for more rapid accumulation of sediments than prevails at present. The sequence of the beds is also uncertain. At most a similarity in the local succession of limestone, quartzite, and schist or banded gneiss can be said to exist.

2. The end of the Grenville marine epoch was marked by an uplift of the earth block as the result of thrust. The strata were upturned and locally sharply folded, probably as the result of recurrent periods of crustal stress, with interludes of quiescent conditions. The predominant thrust perhaps came from the Atlantic, as the trend of the structure is usually northeast.

The remains of the igneous intrusions of the early pre-Cambrian are all of deep-seated type. The intrusions have been separated into two groups, according to the relative deformation they have undergone from regional forces. The group that shows the maximum effects of compression and hence is believed to be older (Laurentian) consists of granite and gabbro, interfolded locally with the Grenville. The later group (Algoman), of anorthosite, syenite, and granite, seems to have been intruded

along with the folding, as is shown both by the internal characteristics of the rocks and their little modified structure. It is a fair inference that at the termination of this orogenic disturbance, which was accompanied by the introduction of enormous plutonic masses of varied types into the sedimentary cover, the early pre-Cambrian lands had a rugged mountainous topography.

3. For the whole stretch of Algonkian time, marked by the accumulation of sediments and volcanic flows in the Lake Superior region and elsewhere, no formational record has been found in New York State. The Highlands probably stood well above the waters that invaded the northern and western pre-Cambrian regions, and perhaps they supplied some of the materials that went into the upbuilding of sediments in those areas in Algonkian time. In New York erosion was the chief activity during this interval. The folded sedimentary cover was stripped to miles in depth, so that only the roots of the structural features were left.

4. A renewal of igneous forces took place at the end of pre-Cambrian time. It was of small scope compared to the earlier activity, but it is of interest as indicating a similarity between the conditions of the final pre-Cambrian stage (Keweenawan) of the Lake Superior region and those in the eastern area. The rocks for the most part are diabase, found in small but numerous and widely distributed vertical dikes that cut all the other formations. Their surface or volcanic equivalents, if any such existed, were removed by later erosion.

5. The progress of base-leveling of the pre-Cambrian land was slowed up toward the last by a regional subsidence, which brought the surface near sea level. The downwarping was gradual and except for occasional oscillatory movements between one part of the region and another continued over a long period until almost all of the pre-Cambrian was submerged. This submergence was the last event in pre-Cambrian time. The sediments that were laid down in the invading seas start the Paleozoic record. Between them and the last previous sedimentation, the Grenville, is the longest hiatus in the stratigraphic column. The Paleozoic beds lie across the eroded edges of the Grenville, marking a structural and erosional unconformity that permits only occasional glimpses of what took place in the corresponding interval.

Paleozoic time.—Submergence of the pre-Cambrian surface in the early stages did not extend far into New York State. During the Cambrian period the Adirondacks were above sea level and still undergoing erosion, whereas western New England and a strip along the eastern border of the State, extending about to the Champlain-Hudson Valley, was below the sea and receiving detritus. The marine invasion came from the east, and the shore line advanced westward with the downwarping in that

direction. The first notable transgression into the Adirondack region occurred in Potsdam time. Then began the deposition of quartz conglomerate and sandstone in shallow marginal seas, starting on the east side of the region and moving around the north and south borders until in the last stage all but the western margin and the central area were covered. The inequalities of the pre-Cambrian surface were smoothed out by the overlapping beds, so that in the succeeding stages of submergence the seas advanced over a level plain. At the end of Potsdam sedimentation there was a change in the conditions, shown by alternation of sandstones with layers containing more or less dolomite which pass into solid dolomite with small amounts of quartz. The dolomite marks the Little Falls stage, which is represented over about the same area as the Potsdam, except on the north side of the Adirondacks, where a warping uplift brought the surface above the sea. The Beekmantown, also dolomite, represents a rather local downwarping in the Champlain sector.

With the Ordovician period the marine invasion extended its limits so that at one time or another deposits were laid down over most of the State. Only the highest Adirondacks and perhaps the southeastern Highlands stood out during the Trenton epoch, when the waters had their maximum spread. In the later stages oscillations due to crustal warping confined sedimentation to distinct regions and to the deposition of detrital materials for the most part (Utica, Frankfort, Pulaski, and Oswego beds). At the end there was a complete withdrawal of the seas, with an uplift that raised the eastern area permanently into land.

The Taconic revolution, as this disturbance is usually called, involved a segment from the St. Lawrence River through western New England south to Maryland and Virginia, extending west into New York State as far west as the Champlain-Hudson Valley. The Cambrian and Ordovician beds were folded into a succession of anticlines and synclines, with their major axes trending north-northeast. The folds were strongly compressed in the central region and overthrown so that they merge into great thrust faults. These thrusts are to the west, and displace the formations in meridional blocks for distances as great as several miles. More or less metamorphism accompanied the compression. The deformation, no doubt, produced effects upon the adjoining area to the west by broad uplift or by local displacements. The Adirondacks were not involved in folding but were doubtless rejuvenated to some extent by uplift. The faults that outline their eastern and southern margins were possibly initiated at this time, although the evidence as to their age is not conclusive. They may have resulted from the Appalachian disturbance at the end of the Paleozoic era.

The Silurian formations in the east overlap the upturned and eroded Ordovician, but in central New York there is little evidence of discordance. The earliest of the Silurian deposits as here identified (the Queenston shale and the overlying beds) were formed in the shallow marginal sea that lay to the south of the Canadian upland and overlapped it. The sandstone layers may be estuarine deposits. Shallow waters also characterized Clinton time, but the basin of deposit reached much farther out than in the preceding stage. Then came still wider and deeper submergence, when the Niagaran limestones and dolomites, largely reef formations, were deposited. In Salina time the interior basin was cut off from the open sea and the waters were evaporated to the point where the dissolved salts were deposited, receiving, however, much land wash from the east in the early part of the period (Vernon shale). Renewed sinking brought the sea once more into the central and eastern parts of the State, with the accumulation of a series of limestones that was to continue through the last stages of the Silurian into the Devonian period.

There was no interruption in sedimentation, so that in places the separation of the two systems upon a stratigraphic basis is hardly possible. The first Devonian beds (Helderbergian) were deposited in the eastern area, but in the Oriskany and Onondaga stages the submergence extended well over the State and into the adjoining regions. Thereafter began the accumulation of shales and sandstones that continued, almost without interruption by calcareous deposition, throughout the Upper Devonian and into Carboniferous time. These beds were laid down for the most part in marginal seas which spread southward from the Canadian and Adirondack uplands and westward from the Taconic folded region. Fresh-water or estuarine conditions prevailed for a considerable time in the eastern part (Oneonta, Catskill beds).

The Devonian period ended without any regional disturbance, and the Carboniferous beds lie upon the Chemung in concordant arrangement.

The extent of the Carboniferous submergence is in doubt. Only the lower formations, including the Mississippian and the conglomerate below the Pennsylvanian coal measures, are now found in outcrop. It is probable that these beds once extended well into the interior and were later eroded away.

The Paleozoic sedimentation came to an end with the Appalachian revolution. This widespread crustal upheaval raised the whole interior region into a land surface. Folding was not an important feature in New York State. The broad belt of folded mountains to the south (the Blue Ridge) gives out before reaching the southern border; only a few ridges, notably the

Shawangunk and Schunemunk Ridges in the extreme eastern section, show mildly deformed beds and reach the Hudson River. Slight archings in the Finger Lake district represent the extent of the folding in the central and western parts of the State. The general effect of the uplift was to form a broad plateau with little differential movement and with the beds preserving the slight dip to the south or southwest acquired from the slowly shelving platform on which they were laid down. The height of this plateau undoubtedly was considerably greater than it is now. Igneous activity was of minor scope. The small peridotite dikes in the central part of the State, which intersect formations as high as the Upper Devonian, were very likely connected with the disturbance. The older uplands had their relief renewed by broad uplift and, inferentially, experienced some displacement along their borders along the fractures that had been earlier established.

Mesozoic time.—At the end of the Paleozoic era the accumulation of sediments in the interior of the State terminated and the whole area was upraised into land. East of the Appalachian folded belt crustal stability was not to be attained until much later. Movements in the way of downwarping, or possibly block faulting, there brought into existence a series of longitudinal troughs in which the waste from the bordering region was washed and deposited. The series of fresh-water beds, lake or estuarine, of Triassic age is now found along the Atlantic coast from Nova Scotia to North Carolina. The Newark beds, as the sediments are called, are in New York State restricted to Rockland County on the mainland and to a small area in Richmond County (Staten Island), the two outcrops being connected by a belt that runs across the intervening part of New Jersey. At the time of their accumulation igneous outbreaks took place in great force in the form of extensive lava flows and in the intrusion of sills and dikes below the surface, all practically of the same type of basic rock, diabase. The Palisades sill, where cut across by the Hudson River, is 1,000 feet (305 meters) or more thick. The Triassic sedimentation was followed by another period of crustal deformation, exhibited mainly in block faulting along northeast-southwest fractures; one series of faults may be traced almost continuously along the western border, between the Triassic and the Highlands belts. The faults are large, and it is reasonable to suppose that the deformation extended well beyond the region now occupied by the sediments. The Cortlandt series of intrusions may be related to the Triassic igneous episode, although in lithologic character the series bears no close relation to the Triassic diabase.

Formations of Jurassic age are absent in New York State; the coastal region was a land surface at the time and undergoing erosion.

At the beginning of the Cretaceous period the physical structure of the present mainland had been practically completed. No further increments in the way of sediments or igneous rocks now to be seen were made during Mesozoic time. Only the Atlantic Coastal Plain, which had been established in its first phase and which in New York State includes a very narrow strip on Long Island and a part of Staten Island, was to undergo submergence and receive deposits. In preparation for the invasion, the land had been worn down during the Jurassic and Lower Cretaceous interval to base-level, so that only moderate subsidence was required to bring it within reach of the sea. It would appear that in the beginning of the Upper Cretaceous epoch the subsidence did not reach sea level, and the sediments accumulated in fresh-water lakes, marshes, and lagoons, near or somewhat back from the coast, as shown by their irregular distribution and the presence in them of land plants. The Raritan clays on Staten Island are an example of this type of accumulation. The later stages of the Upper Cretaceous are locally represented by the Magothy, Matawan, and Monmouth formations, which are of marine character.

The long period of erosion to which the region was exposed after uplift resulted in the development of a peneplain (Cretaceous) that is still apparent in the topography of a considerable part of the State. In the Palisades, the Appalachian folded mountains, and the Taconic area there is a general concordance in the level of the individual peaks which gives an even sky line, though here and there ridges of harder rocks project above the normal level. Similarly there is a degree of uniformity in level of parts of the southern plateau region that seems to reflect this Cretaceous peneplanation (Kittatinny). In the Adirondacks the evidence of base-leveling in Cretaceous time are less apparent, perhaps owing to the marked resistance offered by the massive igneous rocks to erosion and the extreme differences in hardness of the Grenville beds. There is, however, a measure of uniformity in the heights attained by individual groups of mountains in both the Adirondacks and the southeastern Highlands.

The remarkable peneplain of the western Adirondack region belongs to the pre-Cambrian erosion period, preserved by the mantle of Paleozoic sediments that covered the area until the last remnants were removed in the Pleistocene ice invasion. The Catskills, likewise, do not conform to the level of the environing region—in fact, they project high above the Helderbergs on the north and the plateau region to the west, which are composed of

similar beds. Their prominence seems to be the result of a warping uplift that followed the Cretaceous peneplanation.

Cenozoic time.—The end of the Mesozoic era was marked by extensive crustal deformation on the west side of the continent. In the east the effects of the disturbances were confined to a broad uplift of the peneplaned lands, unaccompanied by folding or faulting; as a consequence the Tertiary beds rest upon horizontal unconsolidated Cretaceous strata, with only an erosional unconformity between. There was little change in the marginal area, where the Coastal Plain seems to have oscillated between submergence and elevation slightly above sea level. In the early Tertiary (Eocene) no sediments were accumulated in the local area; but in middle or perhaps late Tertiary time marine clays and sands were deposited over that part of the Coastal Plain now represented by Long Island and Staten Island.

The principal geologic changes to be ascribed to the Tertiary period are those incident to the surface relief—the development of the present topography. The agencies of denudation that set at work on the uplifted Cretaceous peneplain are accountable in a large way for the existing scenic features and drainage pattern over much of the State. The topography before Tertiary time is to a great extent, a matter of inference. There was a notable difference, of course, in the relative altitude of the several structural elements after the Cretaceous peneplanation. The Adirondacks, the southeastern Highlands, and the Taconic Range, with their crystalline rocks, must have stood out prominently, as they do now. The southern plateau was probably reduced to a level surface over which the streams found their way in valleys largely filled with detrital materials. The plateau fell away on the north to a lower plain, marked by the outcrop of the soft Silurian shale formations, on which the drainage was carried by an east-west trunk stream. With the rejuvenation of the land by uplift the Tertiary rivers removed the alluvial accumulations and began to deepen and widen their rock valleys. In this stage, very likely, the Hudson, the Delaware, and the Susquehanna eroded their channels as superimposed streams across the Appalachian barrier, in courses they now occupy. The Hudson River developed its valley between the folded metamorphosed Ordovician rocks and the overlapping Silurian and Devonian beds, with their extensive shaly elements. The Mohawk River similarly followed the boundary between the Adirondack hard formations and the flanking Paleozoic sediments. The Champlain Valley represents a structural depression occupied in Tertiary time by a stream that flowed southward into the Hudson or northward into the ancestral stream of the St. Lawrence. The St. Lawrence in its present volume did not

come into existence until after the Pleistocene drainage diversion and the formation of the Great Lakes. In western New York the Tertiary drainage of the plateau belt was probably carried south by original consequent streams, but that of the plain on the north was probably carried west through a trunk stream (the Dundas River) into the Mississippi. The Mohawk River at that time did not reach farther west than the outlier of pre-Cambrian rocks at Little Falls.

Tertiary erosion accomplished no more than a partial base-leveling of the land. Its effects are fairly well marked along some of the main valleys by rock terraces that lie below the Cretaceous peneplain, more particularly in the plateau district. In the pre-Cambrian areas the Grenville beds alone seem to reveal its influence. The base-leveling was interrupted by rising of the land and the beginning of the Quaternary ice invasion.

The glacial features of the State are generally considered to have been the work mainly of the last of the continental ice invasions—the Wisconsin. Some basis has been found for assuming the existence of one or more interglacial stages, indicative of successive advances and retreats of the ice, but the evidence is not definite enough to establish a correlation with the records in the interior of the continent, where five such advances occurred. The center of ice accumulation in the east was to the north of the St. Lawrence River, on the highlands between the Labrador coast and Hudson Bay, whence the movement spread southward fanwise so as to cover the area between the Atlantic coast and the present Great Lakes. In the maximum advance the whole mainland of New York State was buried under ice, the front lying a little south of the State boundary, in northern New Jersey and Pennsylvania. In the Adirondacks glacial striae are found on the highest mountains, 5,000 feet (1,524 meters) above the level of the marginal area, indicative of at least that thickness of ice. The mountains, however, blocked the movement to a marked degree, so that the main flow was around rather than over the summits. On the south side of the Adirondacks the ice movement converged from the east and west along the line of the Mohawk Valley. Thence the flow was south and southwest over the Catskills and the Devonian plateau.

The extent of the erosion performed by the ice is a debatable question, but in general it would appear to have been limited for the most part to the removal of the soil and rock débris accumulated during Tertiary time. The rock outcrops were freshened, and the valleys in line with the ice movement were widened and deepened.

The overdeepening of the Finger Lake basins may be ascribed with good reason to this agency. Lake Ontario and Lake Erie occupy earlier depressions deepened and extended by the ice, but tilting of the land and blocking of the former drainage by morainal accumulations also entered into their development. Similarly, Lake Champlain and Lake George have been formed in preglacial valleys through erosion and diversion of the drainage. The many small lakes, hundreds in number, which occur over the State have all come into existence as the result of the ice invasion, mainly as the result of glacial scour and the damming of the stream channels by drift.

The retreat of the ice sheet northward led to the formation of many temporary lakes, large and small, whose outlines are traceable by old beaches or by terraced water-laid materials on the sides of valleys. The most remarkable examples of the kind, are the ice-dammed lakes that came into existence as the glacier uncovered in successive stages the basins of the Great Lakes while still spreading over the St. Lawrence outlet. Lake Erie and Lake Ontario were among the last to be uncovered, and until about the stage known as glacial Lake Warren there was no widespread ponding of the waters in New York State in those basins. At that stage the ice had retreated to the north of the plateau, so that the basin of Lake Erie and the marginal area were flooded. The drainage went westward into the Mississippi, but with further glacial shrinkage the outlet into the Mohawk was opened and the waters found their way into the Hudson. With this lowering of the level the Niagara River began to take the flow from Lake Erie and to cut its gorge at the edge of the escarpment at Lewiston. Glacial Lake Iroquois marked a late stage in the recession which has left clearly defined beaches, bars, and deltas above and some distance away from the shores of Lake Ontario. An ice lobe still covered the St. Lawrence Valley, flooding the waters to the level of the Mohawk escapeway. Then came final withdrawal of the ice from the northern border of the State, with abandonment of the Mohawk outlet for that of the St. Lawrence. (The guide to the Niagara Falls district (pp. 78–103) gives further information on the glacial history of the Great Lakes.)

There is evidence of considerable crustal movements before and after the ice invasion. The Hudson River below Albany flows over a buried rock channel that deepens toward the south. In the gorge section through the Highlands the fill of sand and boulders amounts to over 500 feet (152 meters). The channel continues out on the coastal shelf for a long distance from the present outlet of the Hudson in New York Bay. The rock cut

was made in late Tertiary or early Pleistocene time and indicates that the land then stood perhaps half a mile (0.8 kilometer) higher than now. Subsidence followed the withdrawal of the ice, and in late Pleistocene time (Champlain stage) the sea entered the lower Hudson and the St. Lawrence Valleys, advancing in the St. Lawrence west into the Lake Ontario basin and flooding the Lake Champlain Basin, where marine vertebrates and shells are to be found in the lowest of the terraced deposits on the lake shores. The terraced clays along the middle course of the Hudson, from Kingston north, can not be definitely correlated with the marine beds in the lower valley; they may belong to a local ponding of the drainage behind a temporary barrier, conveniently described as Lake Albany. The last incident in the record is uplift, leading to the present conditions, with an apparent rise or warping of the surface from south to north.

ALBANY TO BINGHAMTON

By Winifred Goldring

VICINITY OF ALBANY

The city of Albany is situated on the inner lowland of an ancient (Paleozoic), dissected coastal plain. Toward the south and southwest lies the Allegheny Plateau or cuesta, the inface slope of which in the Albany district is formed by the Helderberg escarpment, one of the most striking features of central eastern New York; toward the north and the east are the older folded mountains or oldlands (Adirondacks and Taconic Range). The Helderberg Plateau (pl. 2) is composed of a series of limestones sandstones, and shales that are still nearly horizontal and in much the same position in which they were deposited in late Silurian and Devonian seas. These beds constitute in large part the earlier Devonian rocks; the Catskills, stretching to the southwest and resting upon the Helderberg formations, are composed of the later Devonian rocks. All these formations once extended northward and eastward across the plains of the Albany district and lapped upon the Adirondacks and Taconic Range. The formations constituting this ancient coastal plain have been gradually worn away, forming an escarpment that has slowly wandered toward the southwest, away from the older folded mountains, getting higher at the same time with increased distance from the old shore line. The lowland is now occupied by the Mohawk and Hudson Valleys. (See fig. 1.)

The Albany lowland has an altitude of 200 feet (61 meters) at Albany and rises gently westward to 300 or 400 feet (91 to 122 meters) and eastward to about 600 feet (183 meters) at the

FIGURE 1.—Outline map of eastern New York showing the location of the oldland, inner lowland, and cuesta of the ancient (Paleozoic), dissected coastal plain

base of the Rensselaer grit plateau. It shows distinctly the character of an erosion plane, cutting across Lower Cambrian and Ordovician formations regardless of rock structure. This is the lowest or Albany (Somerville) peneplain, which was developed in late Tertiary time, before the advance of the ice sheet. Above this peneplain rise numerous hillocks which owe their existence to harder rocks, such as grits or chert beds. The bedrock underlying the lowland is covered with boulder clay, sand, and gravel deposited by the ice sheet and with stratified clay laid down at lower levels in glacial Lake Albany. Subsequent uplift allowed the present Mohawk and Hudson Rivers to cut deeply below the general level. The Hudson River has returned in general to its old preglacial course in the glacial moraine and the postglacial clays and sands of Lake Albany.

To the east of the Albany district the Rensselaer grit, of Upper Devonian age (9),[4] forms an eastern highland, known as the Rensselaer grit plateau. Between this highland and the Helderberg Plateau the formations are arranged in belts running in a general north-northeasterly direction. These belts comprise two different sets of formations (9) laid down in two troughs more or less separated from each other, possibly by a longitudinal bar, and designated the eastern (Levis) trough and the western (Chazy) trough (10). Principally through folding and overthrusting along numerous fault planes, the rocks of the eastern trough have been carried westward, and the formations of both troughs are now in close contact. In the eastern trough are Lower Cambrian rocks, the Schaghticoke and Deepkill shales (Canadian), the Normanskill shale (Lower Ordovician), and the Snake Hill (Middle Ordovician) shales (eastern equivalent of the Canajoharie shale); in the western trough, the Canajoharie shale and Schenectady beds (Middle Ordovician), the Indian Ladder beds (Upper Ordovician), and the Silurian and Devonian formations constituting the Helderberg Plateau. (See stratigraphic table, p. 6, and New York State Museum Handbook 10.)

ALBANY TO THE HELDERBERGS

Westward from Albany the New Scotland Avenue highway passes over the Middle Ordovician Snake Hill shale for a distance of about 6 miles (9.6 kilometers) beyond the city limits, but no outcrops are to be seen. Near the outskirts of the city to the southwest (left) may be had on a clear day a splendid view of the Helderberg Plateau, with the Catskills beyond

[4] Numbers in parentheses refer to bibliography, pp. 38–39.

rising above it. The Helderberg hills and ridges rise to a general level, so that their tops, from a distance, form a distinct sky line, above which is seen a second distinct sky line formed by the tops of the Catskill Mountains. The Helderberg hills and ridges, with an average height of 1,800 to 2,000 feet (549 to 610 meters) represent the remnants of a more or less dissected plateau—the second (Harrisburg) peneplain of the Albany district, of early Tertiary (Eocene) age. This peneplain once extended across the Hudson Valley, and remnants may be seen in the tops of the Grafton and Stephentown hills (Rensselaer grit plateau) in the east, with an average height of 1,600 to 1,800 feet (488 to 549 meters). The third and highest peneplain (Kittatinny) in the Albany district is seen in the even tops of the Catskill Mountains, now at an altitude of about 4,000 feet (1,219 meters). This peneplain of early Cretaceous age was once a low plain extending widely over the East. Remnants of it are present in the tops of the Adirondacks and the Taconic and Green Mountains.

About 2½ miles (4 kilometers) west of the Albany city limits the road dips down into the valley of the Normanskill, deeply eroded in soft Albany clays. On the other side of this valley, at the left, is a small area of sand hills that were once wandering sand dunes before vegetation reclaimed the desert left by the ice sheet and Lake Albany.

From a point 1 mile (1.6 kilometers) west of the village of Slingerlands the road runs over the Schenectady beds, with the first exposure in a road cut about 1 mile outside the village of New Salem (Mount Pleasant Cemetery). The Schenectady beds have a thickness of over 2,000 feet (610 meters) and consist of grits and sandstones with interbedded black and gray shales, the two forming a uniformly alternating series throughout this great thickness, which is due to rapid deposition in a basin formed by a sinking foreland in front of the rising Green Mountain folds, to the east. Fossil evidence favors the Trenton age of the Schenectady beds, and the Utica aspect of a portion of the fauna is undoubtedly due to the shaly facies. On the whole the beds are very barren. The peculiar seaweed *Sphenophycus latifolius* is characteristic and is well distributed through the whole thick formation. Eurypterids, the most striking element of the fauna, have been found in shale layers between sandstone beds and, like the seaweed and some of the graptolites, are well distributed throughout the formation. Graptolites are found in the black shales.

THE HELDERBERGS

From the Schenectady cut the road passes on to New Salem, above which rises the escarpment of the Helderbergs. The section from the base at New Salem to the top of Countryman Hill is as follows:

Middle Devonian:
- Erian—
  - 15. Hamilton shales and flags.
  - 14. Marcellus black shale.
- Ulsterian—
  - 13. Onondaga limestone.
  - 12. Schoharie grit.

Lower Devonian:
- Oriskanian—
  - 11. Esopus grit.
  - 10. Oriskany sandstone.
- Helderbergian—
  - 9. Becraft limestone.
  - 8. New Scotland shaly limestone.
  - 7. Kalkberg limestone.
  - 6. Coeymans limestone.

Upper Silurian:
- Cayugan—
  - 5. Manlius limestone.
  - 4. Rondout water lime.
  - 3. Brayman shale (considered by some a residual soil at top of Ordovician).

Upper Ordovician:
- Cincinnatian—
  - 2. Indian Ladder beds.

Middle Ordovician:
- Mohawkian—
  - 1. Schenectady beds.

The Helderberg Plateau is composed of a series of limestones, sandstones, and shales, in large part earlier Devonian; the Catskills, stretching to the southwest, are composed of the later Devonian rocks. The strata have a southerly dip west of Albany, giving an east-west direction to the escarpment west of Altamont (about 5 miles (8 kilometers) northwest of New Salem). Eastward in Albany County the dip changes gradually to southwest, so that the escarpment takes a southeasterly direction east of Altamont. This southwest dip is very gentle—in the eastern Helderberg area about 100 feet to a mile (19 meters to a kilometer)—and it carries the outcropping edges of the Coeymans limestone, which forms the top of the Helderberg cliff, from an altitude of 1,200 to 1,300 feet (366 to 396 meters) above sea level south of Altamont to about 800 feet (244 meters) above New Salem. Farther south the dip of the beds gradually decreases, the direction of dip changes to almost due west, and the formations are brought down to the general level of the

THE HELDERBERG ESCARPMENT, INDIAN LADDER REGION

Upper Ordovician to Middle Devonian rocks. Indian Ladder beds (lower right) of Ordovocian age; Brayman shale, Rondout water lime, and Manlius limestone (in cliff) of Silurian age; Coeymans limestone (in cliff) to Hamilton beds (hills in background) of Devonian age. Photograph by E. J. Stein.

A. ITALY HOLLOW, NEAR NAPLES, NEW YORK

One of the glacially eroded valleys, with oversteepened sides, in the central southern New York plateau. The higher summit, at the left, 2,000 feet (610 meters) above sea level, is a remnant of the Kittatinny peneplain. Photograph by A. W. Abrams.

B. INTERGLACIAL GORGE, KASHONG CREEK, NEAR BELLONA, NEW YORK

This occurrence is significant in that its location inside and above the general level of the floor of a larger valley makes improbable a hypothesis that the gorge was cut because of a preglacial uplift and rejuvenation of valleys. Photograph by O. D. von Engeln.

country and show folds and faults (more pronounced southward) that belong to the Appalachian revolution. In the eastern part of the Helderberg Plateau the folds, if they occur at all, are very gentle.

From the front the Helderberg Mountains give the appearance of a solid plateau breached only by a few creeks. Back of the cliff and the terrace formed on the Coeymans limestone at its top are the terraces of the Becraft and Oriskany formations and then of the Onondaga limestone. Behind these terraces rise the long, fairly rounded, well-wooded hills formed by the Hamilton shales and flags, with heights of about 1,700 to 1,800 feet (517 to 549 meters) just back of the cliff. In these hills the general southwest dip slope of the country is discernible. Farther to the west the hills rise to an altitude of 2,000 feet (610 meters) or more and embrace a higher formation of rocks, the Oneonta beds, which continues into the Catskill Mountains.

In the New Salem section the Indian Ladder beds are exposed in the ravines leading up from the village to the State road above. Here is about 80 feet (24 meters) of gray and black, partly sandy shale. In the first brook, 30 feet (9 meters) below the base of the Manlius, is 15 feet (4.5 meters) of the yellowish-weathering, calcareous intercalations so characteristic of the lower beds. The Indian Ladder beds are younger than the Utica (of Eden, Upper Ordovician, Cincinnatian age). If there is no hiatus between the Schenectady and Indian Ladder beds corresponding to the Utica shale, it is to be inferred that at least the upper part of the Schenectady is of Utica age, although the fauna does not support this view.

A short distance beyond this locality the road passes a quarry in the Manlius ("Tentaculite") limestone, which is typically a thin-bedded dark-blue, light-weathering limestone of fairly pure composition, about 45 to 50 feet (14 to 15 meters) thick in the Helderberg and Schoharie regions. As many as three *Stromatopora* zones (*Syringostoma barretti*) occur here, one 8 or 9 feet (2.4 to 2.7 meters) thick. These zones, representing reefs, stretch through the Helderbergs at various levels and suggest that the Manlius limestone was deposited chiefly on tide flats in a lagoon behind coral reefs. The fauna of the Manlius is a meager one but includes as common species *Tentaculites gyracanthus*, *Leperditia alta*, and *Spirifer vanuxemi*.

In the field above the Manlius quarry the Coeymans ("Lower Pentamerus") limestone crops out and may be recognized by the characteristic brachiopod *Pentamerus galeatus* (now *Sieberella coeymanensis*). In both the Helderberg and Schoharie areas this limestone has a thickness of about 50 feet (15 meters)

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and is the principal cause of the Helderberg cliff. It is bluish gray, weathering light gray, and of rather coarse semicrystalline texture. Other fossils to be looked for are the brachiopods *Uncinulus mutabilis* and the long-range *Atrypa reticularis*. The coral *Favosites helderbergiae* is fairly common.

From the Manlius quarry the road turns to the right along the east slope of Countryman Hill above the Coeymans-Manlius cliff, crossing the Kalkberg and following the New Scotland beds most of the way to the Indian Ladder area (John Boyd Thacher Park), with several cuts along the road at the left. The New Scotland limestone in fresh exposures has a dark bluish-gray color and massive appearance, but when weathered the color is gray or gray-brown. The Becraft limestone forms a fairly conspicuous cliff along the left side of the road above the New Scotland, and in places the Onondaga may be well seen as a prominent cliff capping the soft Esopus shales. The Schoharie grit crops out in several places beneath the Onondaga cliffs in Countryman Hill, but in the Helderberg area it is very thin (about 3 feet, or 0.9 meter) and not everywhere continuous. This formation in the Schoharie area, though only 5 or 6 feet (1.5 to 1.8 meters) thick, has yielded a wealth of fossils, of which the mollusks are the most striking, particularly the cephalopods.

About 3 miles (4.8 kilometers) beyond the Manlius quarry there is a road-metal quarry in the Esopus grit at the left of the road. The Oriskany sandstone forms the base of the quarry, and the Becraft may be studied in the woods and field at the right.

The Becraft limestone ("*Scutella*," "Encrinal," "Upper *Pentamerus*" limestone) in typical exposures is characterized by numerous crinoid bases or Scutellas (*Aspidocrinus scutelliformis*) and also carries the characteristic brachiopod *Sieberella* (*Pentamerus*) *pseudogaleata*. Other fossils to be looked for are the brachiopods *Spirifer concinnus*, *Schizophoria multistriata*, and *Uncinulus nobilis* and the gastropod *Trematonotus profundus*. In the Countryman Hill section above New Salem there is a thickness of only 13 feet (3.9 meters), and in the Schoharie area only 15 feet (4.6 meters), but southward the Becraft gradually thickens to a maximum of 45 feet (13.7 meters). This massive limestone, usually tending to form ledges, is here shown, like the Coeymans, broken up into blocks by intersecting systems of widely opened joint cracks. Farther to the southeast (middle Hudson area, Catskill and southward) the Alsen limestone, 20 to 50 feet (6 to 15 meters) thick, and the Port Ewen shaly limestone, 5 or 6 feet (1.5 to 1.8 meters) at Catskill to 200 feet (61 meters) in southeastern New York,

intervene between the Becraft and the Oriskany; in the Schoharie area the Alsen, 10 to 15 feet (3 to 4.5 meters) thick, intervenes; but here the Oriskany, 18 inches (45 centimeters) thick, rests directly upon the Becraft.

The Oriskany represents shore deposits of a transgressing sea and at the type locality (Oriskany Falls, Oneida County) is a white fossiliferous quartz-sand rock, 20 feet (6 meters) thick. In the Helderberg area (4 feet, or 1.2 meters) and Schoharie area (5 to 6 feet, or 1.5 to 1.8 meters) the exposures likewise show a hard quartzitic sandstone with a strong admixture of lime grains, very dark bluish gray when fresh and weathering to a brown porous sandrock. Where the beds are fairly horizontal the rock, owing to its flinty nature, forms level platforms or terraces showing, as here, surfaces covered with the characteristic worm burrows, *Taonurus cauda-galli*, or "cocktails" and broken up into blocks by intersecting joint systems. Southward the Oriskany thickens and becomes more calcareous until in southeastern New York (Orange County) there is a thickness of 180 feet (55 meters), with highly fossiliferous limestone beds at the top (Glenerie limestone). Among the characteristic fossils are the brachiopods *Spirifer arenosus*, *S. murchisoni*, *Hipparionyx proximus*, and *Rensselaeria ovoides* and the gastropods *Strophostylus expansus* and *Platyceras nodosum*.

The Esopus ("Cauda-galli" or "cocktail") grit, as shown here, breaks down very readily into gravel. Like the Oriskany, it shows burrows of *Taonurus cauda-galli* on its bedding planes. The Esopus is confined to the eastern part of New York and has a thickness of 80 to 90 feet (24 to 27 meters) in the Schoharie area, 100 to 120 feet (30 to 37 meters) in the Helderberg area, and about 700 feet (213 meters) in southeastern New York (Orange County). These beds are practically barren. A small brachiopod has been reported from the Helderbergs.

About a quarter of a mile beyond the Esopus gravel pit the road passes through a New Scotland cut and crosses one of the few small faults of the northern Helderberg area, having a displacement of about 55 feet (17 meters).

A mile (1.6 kilometers) beyond the fault the road reaches the edge of the Helderberg cliff in the vicinity of Minelot Falls, John Boyd Thacher Park. Here can be obtained a splendid view of the inner lowland stretching to the east and north toward the Adirondacks and the Taconic and Green Mountains.

Minelot and Outlet Brooks tumble as falls over the Coeymans-Manlius cliff in a large reentrant (Indian Ladder Gulf) south of the Indian Ladder road. A similar gulf (Cave Gulf), no longer occupied by a stream, lies just to the north. These gulfs in Tertiary time (1) were eroded by large streams that

drained the Thompsons Lake area. The formation of the Thompsons Lake sink in the Onondaga limestone, together with the southwest dip of the strata (here 35 feet to the mile, or 6.6 meters to the kilometer) diverted the drainage underground, effacing the stream that flowed through the northern gulf and greatly reducing the volume of the streams that flowed through the southern gulf. Thompsons Lake, 1 mile (1.6 kilometers) to the west, occupying the northern extension of the long sink, has an underground outlet in a small cave at the south end through wide solution fissures, the water coming to the surface again in a deep spring 1½ miles (2.4 kilometers) to the southwest.

From the cliff edge at Minelot Falls or in the vicinity of the Indian Ladder road the traveler may look down into Indian Ladder Gulf and see the type section of the Indian Ladder beds, which here have a thickness of 400 feet (122 meters) but rapidly dwindle to nothing toward the north and south. They are a series of alternating argillaceous shales and sandstone beds (the sandstones particularly abundant and thick in the upper portion), with intercalations of very characteristic thin rusty-looking calcareous sandstones between gray shales in the second 100 feet (30 meters). The restricted horizontal east-west distribution of the Indian Ladder beds suggests that they represent an independent northward advance of the Eden sea in one of the long troughs that were being developed in the Appalachian region. These beds have an extremely barren aspect. The black shales yield graptolites (*Dictyonema arbusculum*, *Dicranograptus nicholsoni*); in the calcareous intercalations may be sought such forms as the bryozoan *Hallopora onealli*, the brachiopods *Rafinesquina ulrichi* and *Dalmanella multisecta*, and the trilobite *Cryptolithus bellulus*.

Along the base of the cliff at Outlet and Minelot Falls, between the base of the Manlius and the thick sandstone beds that mark the top of the Indian Ladder formation, occur thin representations of two Silurian formations. The Brayman shale, which has its maximum thickness of 40 feet (12 meters) in Schoharie County, has here a thickness of 2 feet 4 inches (0.7 meter). It consists of unfossiliferous olive-green or grayish clay shales loaded with concretions of iron pyrites of all sizes. By some it is regarded as of Upper Silurian (Salina) age, by others as a residual soil at the top of the Ordovician. The Rondout water lime is represented by 3¾ to 4¾ feet (1.1 to 1.4 meters) of drab impure magnesian limestone with shaly intercalations, weathering brownish. From the Howes Cave area (Cobleskill) has been reported the coral *Favosites helderbergiae* var. *precedens*, which has passed up from the Cobleskill below (missing here), establishing the Silurian age of this water lime.

The Indian Ladder road from the last rise to the four corners about half a mile (0.8 kilometer) directly west gives an almost complete section from the upper Manlius beds to the top of the Oriskany and continuing westward crosses the Esopus and Onondaga. In the Indian Ladder cut are shown the "battlements" formed by the Coeymans limestone (55 feet or 17 meters) and the upper Manlius beds. Above the typical Manlius with the characteristic fossils is a thin bed of water lime, and above this 14½ feet (4.4 meters) of transitional beds now regarded by some as Devonian. Above the uppermost heavy *Stromatopora* zone the characteristic *Gypidula* (*Pentamerus*) *galeata* (now *Sieberella coeymanensis*) appears, marking the base of the Coeymans.

Above the Coeymans cliff is a low terrace, formed on what were formerly known as transition beds between the Coeymans and the New Scotland, carrying a mixed Coeymans-New Scotland fauna. These beds, here about 22 feet (6.7 meters) thick, have recently been separated as the Kalkberg limestone, characterized by parallel seams of chert which form thick beds in the type section (Catskill; 40 feet or 12 meters). The lower beds are marked by the characteristic brachiopod *Bilobites varicus*, and the upper beds by an abundance of bryozoans.

The New Scotland shaly limestone ("Catskill shaly," "*Delthyris* shaly," or "Lower shaly"), with an average thickness of 100 feet (30 meters), is the most fossiliferous member of the Helderbergian series and consists of thin-bedded, very impure shaly limestones and calcareous shales. A typical collection of fossils may readily be gathered here in the middle and upper beds, among them the brachiopods *Spirifer* (*Delthyris*) *macropleura*, *S.* (*Delthyris*) *perlamellosus*, the long-range *Leptaena rhomboidalis*, *Stropheodonta* (*Leptostrophia*) *becki*, *Rhipidomella oblata*, *Meristella laevis*, and *Eatonia medialis;* pelecypods, as *Actinopteria textilis;* gastropods, as *Diaphorostoma ventricosum*, *Platyceras spirale* and *P. ventricosum;* and the trilobites *Dalmanites pleuroptyx* and *Phacops logani*. The sponge *Hindia inornata* is found all through these beds.

At the four corners is shown 9 feet (2.7 meters) of Becraft resting upon the New Scotland beds and overlain by 30 inches (0.76 meter) of Oriskany. The Becraft exposure represents the lower part of the formation. In the crevices in the Oriskany may be obtained the characteristic fossils, which can be successfully collected only in weathered material.

From the four corners the road turns southwest, with a detour to the right to Thompsons Lake 1½ miles (2.4 kilometers) beyond the corners. At the turn the southern extension of the Thompsons Lake sink may be seen at the left. The southern portion of

the lake is surrounded by the Onondaga limestone, which crops out along both sides of the road. The abundance of corals (*Zaphrentis*, *Favosites*, *Eridophyllum*, etc.) found in the outcrops here attests the coral-reef nature of this formation.

From Thompsons Lake the route turns southwest to East Berne over the till-covered Marcellus black shale area. First at the left (east) and then straight ahead (south) are seen the hills formed on the Hamilton shales and flags, with their gentle southwest dip slopes. About 3 miles (4.8 kilometers) from the lake the road crosses a branch of Fox Creek which drains the pool (about a quarter of a mile (0.4 kilometers) to the right) in which the drainage from Thompsons Lake finally reaches the surface. At East Berne the road, still on the Marcellus black shale, turns to the right (west), and from this point it follows down the valley of Fox Creek into the Schoharie Valley. The Hamilton hills stretch along the valley at the left and in their level tops show remnants of the early Tertiary (Harrisburg) peneplain.

Good outcrops of the Marcellus black shale, the lowest of the Hamilton beds, occur about 1 mile (1.6 kilometers) east of East Berne and in the ravines and road cut in the Hamilton hills at the south, between East Berne and Berne, but none are easily accessible. Here are 170 to 180 feet (52 to 55 meters) of black bituminous, pyritiferous, very fissile shales with a meager fauna characterized by the brachiopods *Leiorhynchus limitaris*, *L. mysia*, and *Chonetes mucronatus*, the small pelecypod *Lunulicardium marcellense*, and the minute, needlelike pteropod *Styliolina fissurella*. In the Schoharie region and farther west there are near the base calcareous layers characterized by goniatites, the Cherry Valley (*Agoniatite*) limestone. The Marcellus black shale is succeeded by a series of sandy shales and sandstones which, as indicated by the character of the rock and the fauna, were deposited in shallow waters with shifting currents. These beds represent the upper Marcellus and at least part of the Skaneateles formation. It has been suggested that part if not all of the Sherburne sandstone of the Schoharie Valley represents the Moscow formation and at least a portion of the Ludlowville.

Between 700 and 800 feet (213 to 244 meters) of Hamilton shales and flags are shown in the hills between East Berne and Berne. Farther west, southwest of West Berne, the thickness of the Hamilton, including the Marcellus black shale, has been estimated at 1,415 to 1,720 feet (431 to 524 meters); in the Schoharie Valley the thickness is 1,500 feet (457 meters), exclusive of the Marcellus black shale. Westward the character of the Hamilton beds changes, the sandy shales and sandstones of

the east giving place to equivalent calcareous shales and limestones. The Hamilton fauna (prevailingly brachiopods and pelecypods) is very rich. It is characterized by the brachiopods *Spirifer mucronatus*, *S. granulosus*, *Athyris spiriferoides*, *Chonetes coronatus*, and *Tropidoleptus carinatus;* the pelecypods *Pterinea flabellum*, *Modiomorpha mytiloides*, *Grammysia bisulcata*, and *Goniophora hamiltonensis;* the gastropods *Loxonema hamiltoniae* and *Bembexia sulcomarginata;* the cephalopod *Orthoceras crotalum;* and the trilobites *Phacops rana* and *Homalonotus* (*Delphinocephalus*) *dekayi*. *Heliophyllum halli* is a characteristic coral.

About half a mile (0.8 kilometer) east of Berne the Onondaga again appears and is well shown in the falls of Fox Creek at the entrance to the village. Less than 1 mile (1.6 kilometers) beyond Berne, where the Switz Kill Valley opens into the valley of Fox Creek, on the left side of the road, is a road-metal quarry in the Onondaga, a moderately pure light-bluish limestone. Although thin-bedded in some portions, this limestone is in general massive and here shows the characteristic parallel layers of chert, 4 to 6 inches (10 to 15 centimeters) or more thick. Like the other Helderberg limestones, it is traversed by intersecting systems of joints, which weather out into broad, deep fissures. The Onondaga has a wide distribution, extending with uniform character from the southeast across the State into Ontario, Canada. Its greatest thickness (150 to 200 feet, or 46 to 61 meters) occurs in the western part of the State; in the Schoharie area there is 100 feet (30 meters), in the northern Helderbergs 85 to 100 feet (26 to 30 meters), and in southeastern New York (Kingston area) 50 feet (15 meters). Species of *Favosites* are particularly to be sought in this quarry, but other corals (*Zaphrentis*) will be found. The index fossil of the Onondaga is the brachiopod *Amphigenia elongata;* other brachiopods are *Spirifer duodenarius*, *Stropheodonta hemispherica*, *Meristella nasuta*, and *Pentamerella arata*. Gastropods include the large and striking *Platyceras dumosum;* cephalopods, both coiled (*Gyroceras*) and curved (*Cyrtoceras*), prevail; and trilobites are represented by species of *Phacops*, *Dalmanites*, and *Lichas*.

From this point on the road following down the Fox Creek Valley passes over lower and lower formations, with the Hamilton Hills always on the left. At West Berne the Onondaga disappears in the valley. A mile and a quarter (2 kilometers) west of this village, where the road follows close to the stream, an exposure shows the upper New Scotland in the stream, followed in the road cut at the left by 13½ feet (4 meters) of typical Becraft. Above this is 4½ feet (1.4 meters) of darker fine-grained cherty limestone which has been referred to the Alsen,

originally included in the Port Ewen as a basal phase. It bears the same relation to the Becraft as the Kalkberg does to the Coeymans and carries a modified Becraft fauna. The maximum thickness, 30 feet (9 meters), occurs in southeastern New York. The 10 to 15 feet (3 to 4.5 meters) above the Becraft in Schoharie County, originally classed as Port Ewen, was later referred to the Alsen. Above this cherty Alsen is exposed 5½ feet (1.6 meters) of a drab shaly limestone similar in character and fossil content to the New Scotland. Here is a small representation (12 feet, or 3.7 meters) of the Port Ewen beds ("Upper shaly beds"), which are missing in the Helderberg sections northwest of the Catskill area and have their maximum thickness of 200 feet (61 meters) in southeastern New York.

A little over a mile (1.6 kilometers) beyond this Becraft cut the road passes through a cut in the Manlius, which extends down to the stream bed, with a quarry in the Manlius and Coeymans in the field at the left. The Coeymans may be seen outcropping in the field at the left as far as the bridge over Fox Creek.

In the vicinity of Gallupville the road again passes over the drift-covered Schenectady beds. About a mile (1.6 kilometers) beyond Gallupville, high in the hills at the right, is seen the Coeymans cliff, and a small cliff low in the hills at the left marks the position of the Cobleskill limestone. The Hamilton hills appear in the left distance. The Cobleskill ("coralline limestone") is a thick-bedded semicrystalline limestone characterized by an abundance of corals (*Halysites catenulatus*, *Favosites niagarensis*, *Enterolasma caliculum*, etc.) and species of *Stromatopora*. It is a typical coral facies with reef species.

SCHOHARIE VALLEY

About 7 miles beyond Gallupville the Schoharie Valley appears with West Hill straight ahead. The Coeymans-Manlius limestone, as in the Helderbergs, forms a cliff that may be traced around both West and East Hills, on opposite sides of the valley just where Fox Creek joins Schoharie Creek. A short distance beyond the bridge over Fox Creek, at the right, is seen the old Schoharie fort, which played an important part in the history of this region in Revolutionary and pre-Revolutionary days.

Except for the Indian Ladder beds the same formations found in the Helderberg escarpment occur here, with the addition of the Cobleskill limestone above the Brayman shale and the Alsen limestone above the Becraft. The outcrops of these strata are deflected in loops up the valley, owing to the fact that the beds dip to the southwest. Upstream in the Schoharie Valley higher

and higher beds successively approach the plane of the valley and pass beneath it. The Coeymans limestone crosses the road about a mile (1.6 kilometers) beyond (south of) Schoharie. The Hamilton hills to the east and west of the Schoharie Valley rise to heights of 2,000 feet (610 meters) and over, and the hard beds may be distinguished standing out as cliffs in the steep slopes. The Schoharie region has long been famous for the clear differentiation and normal succession of the rocks of the Helderberg series and overlying beds up to the base of the Onondaga limestone, best studied in East and West Hills.

At Middleburg Schoharie Creek is on the right, and Vroomans Nose appears across the creek in the right distance. From Middleburg to Breakabeen, particularly, and on toward the southwest the route passes up the fertile valley of the Schoharie. This flat valley bottom afforded a haven of refuge for the Palatines, who were forced to leave the English colony of the Hudson River region and settled here in 1713.

Southwest of Middleburg the road winds between hills of Hamilton shales and flags, but in the higher hills appear above these beds first the Sherburne, then the Ithaca, and finally the Oneonta beds of Portage age. Half a mile (0.8 kilometer) beyond the village of Fultonham is a very fine Hamilton cut, with distinct glacial groovings not far above the base. The Sherburne sandstone forms the top of the hill in which this cut has been made. The cliffs formed by the hard flag beds in the Hamilton hills are particularly well shown between Breakabeen and North Blenheim.

The Schoharie Valley continues in Hamilton beds to North Blenheim, where the Sherburne sandstone appears. Just beyond the village and for over a mile (1.6 kilometers) farther along the road bluish sandstones and greenish shales of this formation are seen. They represent a bar formation, which separated the western fauna in central New York from the modified Hamilton fauna in the eastern area of the Atlantic. Fossils where present constitute a modified Hamilton fauna.

The Sherburne flags in the Schoharie Valley, 250 feet (76 meters) thick, are succeeded by the Ithaca formation, a series of shales and sandstones with an average thickness of 500 feet (152 meters) and carrying a modified Hamilton fauna. The Ithaca beds crop out in several places along the North Blenheim-Gilboa road with an excellent section at the Mine Kill Falls, 4 miles (6.4 kilometers) south of North Blenheim. The red and green Oneonta beds are first seen along the road at the top of the hill just east of Gilboa. The Ithaca beds at Gilboa have yielded a fine collection of fossil tree stumps of the seed fern *Eospermatopteris*, a representative set of which is exhibited here.

At Gilboa is the storage reservoir that supplies part of the water for New York City.

In the hills to the east and west of the Schoharie Valley at Gilboa the Oneonta beds appear. The road continues southwestward over this formation to Grand Gorge. The Oneonta beds represent the uppermost Portage in the East. They are a series of red and green shales, reddish sandstones, and coarse grayish to greenish-gray sandstones, nonmarine and nearly unfossiliferous, containing scattered specimens of the mussel *Amnigenia* (*Archanodon*) *catskillensis* and plant remains. With a thickness of about 500 feet (152 meters) in the east-central area this formation gradually increases in thickness eastward until in the mid-Hudson area it completely replaces the Ithaca beds and has a thickness of 2,000 to 3,000 feet (610 to 914 meters).

SUSQUEHANNA VALLEY

From Grand Gorge the road leads from the Schoharie-Hudson drainage basin to the northwest and west across the headwaters of the Delaware River into the great Susquehanna drainage basin. The route passes over the Oneonta beds through Stamford and Harpersfield Center, a distance of about 20 miles (32 kilometers) and then over the Ithaca beds to Oneonta, where the Oneonta beds appear at the higher levels to the north and south.

From Oneonta the road continues almost to Binghamton, in the valley of the East Branch of the Susquehanna, with many typical glacial hills shown on both sides of the road. Cuts in the Oneonta red beds are seen along the road 6 to 8 miles southwest of Oneonta. In the vicinity of Bainbridge the road passes onto the Chemung formation, over which it continues to Binghamton. At Nineveh the road leaves the Susquehanna Valley, and at Port Crane, about 5 miles (8 kilometers) farther, it enters the valley of the Chenango (branch of the Susquehanna). To the left on entering Binghamton may be seen in the distance the plant of the Binghamton Brick Co. The quarry which is the source of this company's material lies in the Chemung shales and sandstones (Cayuta).

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THE FINGER LAKE REGION

By O. D. von Engeln

INTRODUCTION

The Finger Lake region may be termed the heart of the Devonian, for it presents a section of the whole Devonian system, many of whose members are seen in their type localities. The region owes its name to the presence of a unique group of ten linear lakes, some of whose basins are excavated to great depths. The two largest, each about 40 miles (64 kilometers) long, in the center of the group, may be likened to the thumbs of the right and left hands; the other eight are disposed as the fingers are.

The excavation of the basins of the Finger Lakes and the development of the peculiar pattern of the drainage to the south are direct consequences of the invasion of the region by the ice sheets of the Pleistocene continental glaciation.

The Devonian rocks of the Finger Lake region have a southerly dip—1° to 3° in the north, 7° to 9° in the south. As the altitudes above the sea also rise from north (500 feet, or 152 meters) to south (2,000 feet, or 610 meters), there is an uninterrupted section of the whole Devonian system, about 4,000 feet (1,219 meters) in thickness, in a distance of 75 miles (121 kilometers).

The secondary component of southwest dip, noted in the foregoing description of the Albany district, is continued into the northeastern parts of the central plateau district, and there is a slight dip to the southeast from the northwestern portion of the district, giving a broad, shallow syncline superposed on the dominant southerly monocline. Such a structure is indicated by Keith (11)[5] east of the anticlinal development of the Cincinnati arch.

[5] Numbers in parentheses refer to bibliography, pp. 68–69.

The general southerly dip of the rocks is also interrupted by a series of nearly parallel anticlines and synclines that strike generally east. To the steeper dip of the southern limbs of these folds is in considerable measure to be ascribed the average south dip of the strata. The undulations are low and relatively broad but die out northward south of the line of the outcrop of the Onondaga limestone. In certain of these folds natural gas fields of considerable economic importance have been developed since 1930—the Altay-Wayne field, New York, with an estimated daily production of 250,000,000 cubic feet (7,080,000 cubic meters) in October, 1931, and the Tioga County field, Pennsylvania, with an estimated production of 300,000,000 cubic feet (8,496,000 cubic meters). In October, 1931, it was estimated that the new southern New York field would yield 17,000,000,000 cubic feet (481,440,000 cubic meters) of gas.

A very characteristic feature of practically all the formations within the district is their regular and well-developed jointing. The perfection of expression of this jointing along the eastern shore of Cayuga Lake led to the choice of this site (Hall and Dana) as the standard source for illustrations of the phenomenon.

The glacial fill is deepest in the larger valleys. A boring at Watkins penetrated 1,080 feet (329 meters) of unconsolidated materials. Here the bedrock is over 600 feet (183 meters) below sea level. In general, wells 100 to 200 feet (30 to 61 meters) deep in the floors of the larger valleys fail to reach hard rock. The glacial materials of these deep fills are principally water-deposited or water-modified. The hills and higher slopes are mantled with a much thinner cover of till, which has an average thickness of 2 to 10 feet (0.6 to 3 meters). Besides these widespread deposits there are great ridged morainic masses, chiefly on the line of the east-west divide between the St. Lawrence and Susquehanna drainage basins and principally within the larger north-south valleys. It is undetermined exactly where these moraines belong in the glacial succession. They are commonly referred to as valley-head moraines, but other less pronounced accumulations parallel them at places farther north.

THE SEDIMENTARY SUCCESSION [6]

The southern portion of the central New York section is in the belt of Upper Devonian off-shore deposition. Farther east

[6] K. E. Caster has revised all the stratigraphic and paleontologic items in this paper, added the fossil lists, indicated the best collecting localities, and contributed generously, from the results of his special studies of the Devonian in the area, to this and the following section and throughout the itinerary.

and south the Catskill formation is interpreted as a composite of deltaic and alluvial fan accumulations. Here the deposits of the Catskill sedimentation are seen only at the outer border of the region traversed. The beds below the Catskill are prevailingly off-shore deposits. Some are shallow-water sediments; others were laid down in relatively quiet seas.

One of the phenomena of this deposition is the fourfold recurrence, at successively higher stratigraphic horizons, of a Hamilton fauna containing a characteristic form, *Tropidoleptus carinatus;* hence the name *Tropidoleptus* zones. This fauna is commonly

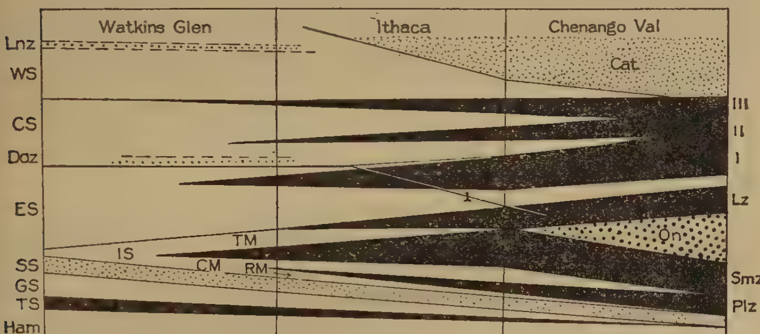

FIGURE 2.—Faunal chart, showing the eastward invasion of the Portage and Chemung faunas and the westward invasion of the recurrent Hamilton faunas in central New York. 1, Base of Chemung type of sediment; I, II, III, first second, and third recurrent *Tropidoleptus* zones; Cat, Catskill deposits; CM, Cascadilla shale member; CS, Cayuta shale stage; Ddz, *Dalmanella danbyi* zone; ES, Enfield shale stage; GS, Genesee shale stage; Ham, Hamilton beds; IS, Ithaca shale stage; Lnz, *Leptostrophia nervosa* zone; Lz, *Leiorhynchus globuliformis* zone; On, Oneonta sandstone; Plz, *Paracyclas lirata* zone; RM, Renwick shale member; Smz, *Spirifer mesistrialis* zone; SS, Sherburne sandstone stage; TM, Triphammer shale member; TS, Tully limestone stage; WS, Wellsburg sandstone stage. (Modified from Williams, 1913.) Drawn by K. E. Caster

considered to have an eastern origin and to have been engaged in a struggle with forms from the west (Portage) for the possession of intermediate areas. The lowest and major *Tropidoleptus* zone appears at the top of the Enfield member of the Portage series, the second is in the middle, the third at the top of the Cayuta member of the Chemung formation. A minor zone is found in the Ithaca shale member of the Portage beds. (See fig. 2.)

These recurrences are ascribed to varying conditions of sedimentation (on a continuously subsiding bottom) that, in turn, are considered to have resulted from a change in temperature and currents within the sea. An alternative explanation is that

the sinking of the basin in which these sediments were deposited was independent of the accumulating load and that the sunken basin was in the nature of a fore deep to the high lands of Appalachia and Laurentia on the east and northeast, though not developed to the depth and sharpness of a fore deep as ordinarily defined. According to this view the greatest deepening was always close to the source from which the sediments were derived. At the end of intervals of marked depression, when the sedimentary fill had overcome the overdeepening in the east and caused a shallowing of waters westward, the Hamilton fauna was extended in that direction. With renewed movement downward in the east the Portage fauna moved eastward over the deeper bottom. However, the site to which the Hamilton *Tropidoleptus* fauna was then forced to migrate is as yet unknown. Meanwhile the far western regions of the inland seas experienced comparatively little change in level of their bottoms, and such change in depth as did take place was uniform over wide areas.

In support of such interpretation is the fact that the paleontologically distinctive Tully limestone terminates eastward in thick sandy layers (though retaining its characteristic fossil *Hypothyridina* (*Hypothyris*) *cuboides*) and westward in pyrite lenses. The pyrite lenses indicate deposition in a shallow basin containing foul water at a site remote from a source of detritus. Trainer's petrographic studies of the Tully limestone (38) show that the detrital portion of the formation had a northeastern source. The presence of scourways with a southwest trend marked by long "channel fillings" of sandstone in the Ithaca shale member of the Portage is similarly indicative of their derivation from the northeast. This is confirmed by Sheldon's studies (36, 37) of the trends of ripple marks in the Portage beds. The succession of limestone, shale, and sandstone, several times repeated in this basin, as exemplified by the Tully, Genesee, and Sherburne beds, is indicative of alternate deepening, by depression, and shallowing, by fill, in the manner suggested.

Beginning at the top and proceeding downward in the section the different units of the Devonian system are described below in approximately the order that they are seen in this part of the excursion. The nature and expression of the other systems at the sections seen in this part of the excursion are described at appropriate points in the itinerary.

DIVISIONS OF THE DEVONIAN

Catskill beds.—The Catskill beds constitute a nonmarine facies consisting of 3,000 feet (914 meters) of sandstones, shales, and conglomerates, chiefly red, which represent in the east the time

equivalent of the Chemung. These red beds spread westward, replacing the marine Chemung beds and continuing into Mississippian time. They are present in the high hills in the southeastern part of the region, around the village of Vestal. West of Tracy Creek the beds have thin cross-bedded shinglelike laminae that are characteristic of the Catskill sedimentation. The rocks are coarse-grained micaceous olive-green sandstones and chocolate-colored shales, duller in color than more representative Catskill material. Fine-pebbled conglomerate beds indicate shore-line conditions. Fossils are rare in the Catskill and consist almost exclusively of fish bones. The fresh-water mussel *Archanodon catskillensis* is characteristic.

Chemung beds.—The Chemung formation has a thickness of 1,200 to 1,300 feet (366 to 396 meters) divided about equally on a faunal basis between the Wellsburg sandstone member above and the Cayuta shale member below.

The Wellsburg member is of coarser texture because it represents the extension of the Catskill beds westward. The shale of the Cayuta member represents the deeper-water sedimentation that persisted farther offshore through several alternating intervals of active depression and still-stand of the eastern fore deep. The upper boundary of the Cayuta shale is marked by the third major recurrent *Tropidoleptus* zone; the lower boundary by the zone of *Dalmanella danbyi*.

In the upper part of the Wellsburg the rocks are characteristically thin-bedded, tough flags, more homogeneous in composition than the Cayuta layers. Some thick-bedded sandstones of Catskill type are present. Here also are lentils of conglomerate with pebbles as much as 2 inches (5 centimeters) in diameter, presumably bars built up by currents. There is also a calcareous sandstone indicative of a diminished supply of detrital material. The Wellsburg is less fossiliferous than the Cayuta shale member.

In the Cayuta shale member the shales are generally drab and argillaceous, and there are intercalated beds of sandstone ranging from 2 to 10 inches (5 to 25 centimeters) in thickness. The characteristic fossil of the Chemung formation is *Spirifer disjunctus* (*S. verneuili*).

Portage beds.—The transition from the Chemung to the Portage rocks is not sharp. Its horizon descends eastward; that is, Chemung deposition began in the east while Portage sedimentation was in progress farther west. The brownish Chemung color changes to a dark blue-gray in the Portage.

There were three sedimentary and bionic provinces in the Portage basin.[6a] (See fig. 3.) The eastern or Oneonta province,

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[6a] Interpretation of J. M. Clarke.

isolated by a bar or currents from the Ithaca province, next west, is characterized by coarse, near-shore or deltaic sediments.

The Ithaca province is characterized by even-bedded sandstones and shales that contain a modified Hamilton brachiopod fauna. The typical exposure of these beds is in the Tioughnioga

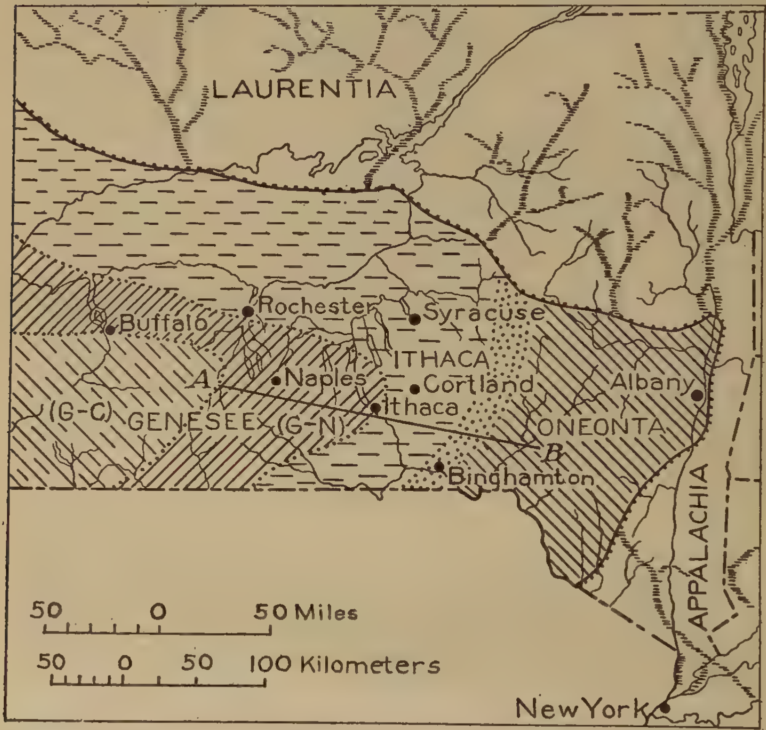

FIGURE 3.—Bionic provinces of New York during Portage time. (G–C), Genesee bionic province, Chautauquan subprovince; (G–N), Naples subprovince. Line A–B indicates position of section in Figure 4; stippled north-south band indicates the supposed position of the Portage sand bar which separated the marine Ithaca province from the estuarine Oneonta. Rochester marks the mouth of the Genesee Valley, Binghamton the mouth of the Chenango Valley. (Modified from J. M. Clarke by K. E. Caster)

Valley and around Cortland, localities about 20 miles (32 kilometers) east of Ithaca. The city of Ithaca is on the border line between the western or Genesee province and the Ithaca province. Both the Ithaca and Genesee facies are represented in the exposure along Cayuga Lake. Figure 4 illustrates the intergradation between eastern and western faunas as seen at Ithaca.

MAP OF FINGER LAKE REGION AND NORTHERN PENNSYLVANIA

Showing ice front at time of forced drainage in Canisteo Valley. Fossil localities indicated by crosses. Drawn by C. H. Hewitt and C. Rappenecker.

The Genesee province is divided into two subprovinces. The one on the east is known as the Naples subprovince and is characterized by a *Manticoceras intumescens* and pelecypod fauna. The western or Chautauquan subprovince is characterized by a prenuncial Chemung fauna.

The border-line position of the Portage beds of the Cayuga Lake meridian is best understood through a study of the sediments and faunas of the Ithaca region. The succession of faunas in the Ithaca region is shown as follows in regular sequence:

Chemung beds:
- Wellsburg sandstone stage—
  - Typical Chemung fauna.
- Cayuta shale stage—
  - *Tropidoleptus* zone No. 3.
  - Chemung fauna.
  - *Tropidoleptus* zone No. 2.
  - Chemung fauna.
  - *Dalmanella danbyi* zone.

Portage beds:
- Enfield shale stage—
  - *Cardiola* fauna (Naples).
  - *Tropidoleptus* zone No. 1.
  - *Cardiola* fauna.
- Ithaca stage—
  - Shale member (Triphammer)—
    - Recurrent *R. laevis* zone.
    - *Cardiola* fauna.
    - Recurrent Ithaca fauna.
    - *Cardiola* fauna.
    - Brachiopod fauna ("Ithaca fauna").
  - Shale member (Cascadilla)—
    - *Cryptonella eudora, Spirifer mesistrialis* fauna.
    - Recurrent Hamilton fauna.
  - Shale member (Renwick)—
    - *Lingula, Cardiola* fauna.
- Sherburne stage—
  - *Reticularia laevis* zone.
  - *Cardiola* fauna.
  - *Cladochonus* (prenuncial Ithaca) fauna.
  - *Cardiola* (Naples) fauna.
- Genesee stage—
  - Pelagic and prenuncial Naples fauna.
- Tully limestone stage—
  - Tully limestone fauna.

The thicknesses of the several members of the Portage and Chemung beds of the Ithaca region will be given in the discussion that follows. The described members of the Portage beds of the Seneca Lake meridian correspond to the Ithaca nomenclature as follows: Genesee stage, 100 feet (30 meters); Sherburne stage, 215 feet (65.5 meters); Ithaca stage, 400 to 500 feet (122 to 152 meters); Enfield stage, 725 feet (221 meters).

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The Enfield shale member is normally characterized by tough arenaceous wave-marked sandstones, 6 to 18 inches (15 to 45 centimeters) thick, and shales that do not yield readily to weathering and are so homogeneous that the joint planes cut them sharply. The Chemung members seen at Owego, Spencer, and West Danby, the lower beds of which cap the hills just south and southwest of Ithaca, are, on the other hand, characterized by soft, coarse-bedded blocky shales, which weather brown and disintegrate into yellow soil. The sparse (pelecypod) faunal content marks the Enfield as a part of the Portage, but except in color it is lithologically like the Chemung. In the western part of the district, where flaggy rocks predominate, the passage of the Portage into the Chemung is more sharply marked. The thickness of the Enfield ranges between 750 and 900 feet (229 and 274 meters). The first recurrent *Tropidoleptus* zone occurs near the top of the Enfield shale member. Except in the *Tropidoleptus carinatus* zone, fossils are rare; the fauna is pre-

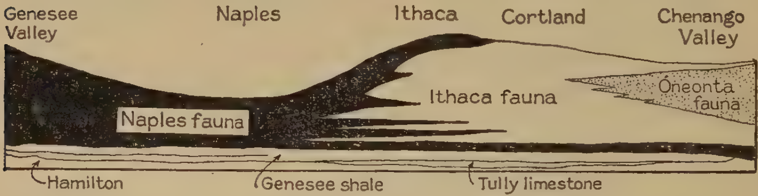

FIGURE 4.—Section across central New York showing the interdigitation of Portage faunas from east to west. (After Clarke; drawn by K. E. Caster)

dominantly of the Naples (*Cardiola*) type. Although there is a general absence of brachiopods, small Productellae are found here and there.

The Ithaca stage consists of three shale members. The lower member is a black shale characterized by a Naples fauna (*Cardiola*, *Orbiculoidea*, and *Lingula*). The fauna of this shale comprises *Lingula complanata*, *Leiorhynchus mesicostalis*, *Styliolina fissurella*, *Orbiculoidea lodensis*, and other species.

This black shale gives way abruptly to a gray shale (the middle Ithaca member), which is characterized by a distinct faunal assemblage. The basal fauna of this shale is of a decided Hamilton facies and constitutes the minor recurrent *Tropidoleptus* zone mentioned on page 41. This shale member is about 200 feet (61 meters) thick in the Ithaca region and has a highly characteristic faunal zone, near the top of which the most significant species are *Spirifer mesistrialis*, *Delthyris mesicostalis*, *Gomphoceras tumidum*, *Cyrtina hamiltonensis*, *Orthoceras bebryx* var. *cayuga*, *Poteriocrinus cornellianus*, *Pleurotomaria capillaria*,

and *Cryptonella eudora*. This fauna is well exposed at the north end of the Stewart Avenue Bridge over Fall Creek (Sphinx Head Temple), at Ithaca.

The upper Ithaca shale member contains the "Ithaca fauna," characterized by the preponderance of brachiopods. This zone of the typical Ithaca is as much as 300 feet (91 meters) thick and is delimited at the top by the appearance of the typical *Cardiola* fauna of the Enfield shale stage. The lower part of this member is characterized by an abundant fauna, including in part *Spirifer mesicostalis*, *Douvillina mucronata*, *Leptostrophia perplana* var. *nervosa*, *Cyrtina hamiltonensis*, *Productella speciosa*, *P. truncata*, *Atrypa* cf. *A. reticularis*, *Schizophoria striatula*, *Cypricardella bellistriata*, *Leiorhynchus mesicostalis*, *Chonetes scitulus*, *C. setigera*, *Palaeoneilo filosa*, *Pterinopecten suborbicularis*, *Leptodesma sociale*, *L. rogersi*, *Actinopteria boydi*, *Modiomorpha complanata*, *Grammysia subarcuata*, *Nucula* sp., and *Buccanopsis leda*. The top is marked by a Sherburne fauna and the recurrence of *Reticularia laevis*, which in this zone makes its last stand in the region. Between these two zones are found many feet of almost barren shales characterized in the main by a sparse Naples (*Cardiola*) fauna, with at least one recurrence of the Ithaca (*Cladochonus*) fauna in the midst of the Naples fauna. This recurrence marks the final withdrawal of the Ithaca fauna from this region. The Ithaca fauna can not be traced much west of Ithaca, but the *Cladochonus* subfauna is found 20 miles (32 kilometers) west, on Seneca Lake. The type section at the head of Cayuga Lake shows 460 feet (140 meters) of the Ithaca member. It thins westward in the Seneca Lake basin. In the type area it is a finely stratified fissile shale, with blue-gray sandstone layers.

The Sherburne flagstone member is made up chiefly of thin-bedded sandstones, especially prominent at the top, with some thin shale partings. It has a thickness of 180 to 260 feet (55 to 79 meters). The Sherburne is not distinguishable much west of Cayuga Lake. To the east, in its typical development, the Sherburne carries a characteristic fauna, one phase of which is seen in the *Reticularia laevis* fauna of Cayuga Lake. At Ithaca, in the cliffs along the southeast corner of the lake, the Sherburne contains a distinct Naples fauna, characterized by *Cardiola* and other pelecypod species. The first significant fauna is the prenuncial Ithaca (*Cladochonus*) fauna, which occurs in the *Cardiola* invasion and is characterized by *Cladochonus* sp., *Spirifer subumbonatus*, *Chonetes lepida*, *Leiorhynchus mesicostalis*, *Grammysia subarcuata*, *Cardiola speciosa*, *Goniatites* sp., *Palaeoneilo filosa*, *Nucula randalli*, *Douvillina mucronata*, and *Coleolus aciculum*. Above the zone of this fauna the pelagic Naples

pteropod-pelecypod (*Cardiola*) fauna continues. Near the top of the 200 feet (61 meters) of the Sherburne the typical *Reticularia laevis* fauna occurs, of which the commonest species are *Reticularia laevis*, *Palaeoneilo filosa*, *Pterochaenia fragilis*, *Chonetes lepida*, *Taxocrinus ithacensis*, *Goniatites complanatus*, *G. sinuosus*, *G. discoideus*, *Porcellia nais*, *Orthoceras pecator*, *O. anguis*, *Cardiola speciosa*, and *Styliolina fissurella.* The *Reticularia laevis* fauna does not extend west of Seneca Lake in New York and may be thought of as the fauna of the eastern phase of the lower Portage beds.

The contact of the Genesee and Sherburne is gradational in the Ithaca region. The Genesee is a massive brownish-black shale that breaks or weathers into smooth, very thin fissile flakes. In the Seneca Lake region the top is a somewhat concretionary and argillaceous limestone; in the Cayuga section the top is sandy. The body of the formation is siliceous rather than argillaceous. In the Taghanic gorge the Genesee is 135 feet (41 meters) thick.

The Genesee shale consists of the finest-textured detrital deposits that can be derived from land erosion and contains much macerated plant material. It becomes coarser eastward and grades into the Sherburne flags. It was probably derived from low-lying land situated to the east, and the absence of any indications of wave marks suggests quiet, comparatively shallow waters as the site of deposition. The fauna of the Genesee is an essentially prenuncial Naples fauna, containing *Orbiculoidea lodensis*, *Styliolina fissurella*, *Chonetes lepida*, *Leiorhynchus limitaris*, *L. quadricostatus*, *Lingula spatulata*, *Tentaculites gracilistriatus*, *Orthoceras subulatum*, *Pterochaenia fragilis*, *Cardiola speciosa*, *Ambocoelia umbonata*, and *Phthonia lirata.*

At the base of the Upper Devonian in this region the Tully limestone followed by the black Genesee shale marks the beginning of a new sedimentary cycle, the Portage beds. A similar cycle is observed in the Trenton limestone followed by the Utica shale, or the Onondaga limestone followed by the Marcellus black shale. The transition between the Genesee shale and the Tully limestone is gradational.

The Tully limestone is a calcareous formation at and west of the type locality. East of the type locality it contains a considerable proportion of detrital material. It is dark gray on unweathered surfaces, owing to its content of carbonaceous matter. Weathered surfaces are light brown to yellow. The Tully is lacking west of Canandaigua Lake. It is 20 feet (6 meters) thick in the Cayuga Basin, but it is 47 feet (14 meters) thick in the Chenango Valley, where it grades into sandstones, shales, and shaly limestones that have the characteristic Tully

fossil *Hypothyridina* (*Hypothyris*) *cuboides* at their base. This world-wide species is associated throughout the exposures of the Tully with an assemblage essentially consisting of Hamilton species, though slight variations from Hamilton types are indicated, and there are a few additional species present like the characteristic trilobite *Bronteus* (*Thysanopeltis*) *tullius*.

The Tully is made up of several beds, the lowest one of which is massive and is rather constantly 3 to 5 feet (0.9 to 1.5 meters) thick, except in the Chenango Valley, where it is only 3 inches (7.6 centimeters) thick. Tully beds are relatively resistant, and the basal bed forms an overhanging cap rock of a vertical waterfall wherever the formation is crossed by a stream draining into one of the glacially overdeepened valleys. The Tully is an easily recognized marker in the stratigraphic series. This fact coupled with the occurrence of the unique *Hypothyridina cuboides* makes it possible to determine with certainty the line of demarcation between the Genesee beds above and the Hamilton beds below.

MICA PERIDOTITE DIKES

Between 25 and 30 dikes of mica peridotite from 1 inch to 5 feet (2.5 centimeters to 1.5 meters) in width have been discovered in the region around Ithaca. Similar dikes crop out near Syracuse and Little Falls. The observed outcrops are all in or below the Portage formation. The rock is nearly black when fresh but weathers first to a yellow-green serpentine and then to a residual clay. The groundmass contains many phenocrysts of garnet, a few of unaltered olivine, and much phlogopite mica.

These dikes invariably follow the north-south joints. The wall rock is little if at all metamorphosed, and included fragments are unaltered. Such inclusions appear to be derived from the beds at or near the level of the observed outcrop of the dike. The intrusion is commonly dated as post-Portage and pre-Permian and associated with the compressional movements that occurred at the time of the Appalachian revolution. There seems no good reason, except their failure to penetrate formations higher than the Portage, why the dikes may not have been introduced as recently as the time of the Tertiary uplifts, when tensional stresses must have been particularly effective.

GEOMORPHIC HISTORY AND ITS TOPOGRAPHIC EXPRESSION

The broad, low synclinal depression described above has been an important factor in the development of this part of the "central New York lowland," which includes the middle and northern sections of the region here described. In plan it has

FIGURE 5.—Sketch map showing basin of central New York, together with sites of scarps, pattern of drainage, and geologic formations. Drawn by Elizabeth Baker

the outline of the letter V, with a rounded apex pointing south, and is flanked on all sides by higher lands rising in a series of disconnected steps or scarps. (See fig. 5.) Another condition that has contributed to the creation of this lowland is the thinning out, from the east and west, of certain of the older, durable formations, notably the Coeymans limestone and the Lockport dolomite.

Furthermore, a series of very weak shale formations appear in the central section. At a higher stratigraphic level, hence farther south, the Tully limestone is effective in upholding the eastern arm of the V where it narrows. But the Tully becomes progressively thinner westward and pinches out to pyrite lenses in the meridian of Canandaigua Lake.

In the long history of post-Permian denudation that the region has undergone there seems to have been at least one period of complete peneplanation, assigned to the Cretaceous. Since then the region has not been completely base-leveled. The existing topography has resulted from the uplift and dissection of the Cretaceous peneplain.

With revival of stream erosion, following the initial uplift of the peneplaned surface, the effect of the synclinal structure described above, together with the lesser measure of durable formations present in the central section, was to promote the development of a broad reentrant between the stronger and higher rock masses on the east and west. A comparatively large volume of drainage would collect within the reentrant thus formed and be directed toward a major drainage line along the axis and would find its outlet northward toward Hudson Bay. In the partial erosion cycles that followed each successive uplift, the embayment was enlarged and its boundaries made more prominent. Farther east the post-peneplain drainage at first was to the southwest, controlled by the position of the Adirondack massif. Thus there was early established a northeastward trending divide between drainage to the north and the south that still in part persists (St. Lawrence-Susquehanna parting).

The changes in level apparently involved an uptilting of the northern lands. Downcutting by the northward-flowing streams easily kept pace with these rises. The southwest drainage, however, had either a very long course, hence low slopes and little erosive effectiveness, to the Mississippi embayment, or was compelled to cross strong rock barriers in order to escape to the Atlantic. Therefore the southward-flowing streams were never able to capture the drainage of the central New York lowland.

On the other hand, the northward-flowing drainage encroached on the territory of the southward-flowing drainage in central

southern New York. The divide migrated south in the direction of the dip, in accordance with the well-known law. The line of the existing divide between the north and south drainage does not everywhere coincide with the trace of the highest altitudes. The disposition and topography of the highest altitudes give indications that their lines were the sites of divides before the preglacial captures that reversed drainage to a northward course, especially the drainage now tributary to the Cayuga and Seneca Valleys. Thus it appears that the Chemung River was turned northward at Horseheads. It should be noted, however, that these diversions were made at levels considerably higher than those of the local base-levels at present. Thus at the head of the Cayuga Basin the preglacial drainage level was at about 900 feet (274 meters) above sea level, whereas the present altitude of Cayuga Lake is 384 feet (117 meters), and the lake has a depth of 430 feet (131 meters).

These diversions in part explain the curvilinear pattern of the east-west drainage within the embayment. The stream trends in the south have a pattern that suggests the design of a Hebrew seven-branched candelabrum. (See fig. 5.) This pattern, initiated by the structure and preglacial stream captures, has been accentuated very greatly by diversions and rearrangements of drainage occasioned by the advances of the Pleistocene glaciers. The lobation of the fronts of the ice sheets was governed, both in advances and in retreats, by the erosional depression. The lobations in turn governed drainage to the south of the ice fronts. Accordingly it is held that the chief factor in determining both the preglacial and the glacial drainage pattern of the area has been the synclinal structure of the central New York basin.

Fridley's studies of the upland levels (48) have led him to the conclusion that the general altitude of 1,700 to 1,800 feet (518 to 549 meters) in south-central New York represents an erosion surface of Tertiary age that is to be correlated with the Schooley peneplain in the Appalachians of Pennsylvania. An older erosion surface, the Kittatinny (Cretaceous), is well preserved in Potter, Tioga, and Bradford Counties, along the northern boundary of Pennsylvania. Remnants of this earlier peneplain are present farther north in New York—for example, on Connecticut Hill, near Cayuta Lake, at an altitude of 2,095 feet (639 meters). These two peneplain surfaces are roughly parallel but have experienced a domed upwarping both in the east (Catskill region) and in the west (northern Pennsylvania and southwestern New York), which has left their surfaces lower in south-central New York than farther east or farther west. (See fig. 6.) Thus the earlier synclinal depression along this north-south axis appears to have been accentuated in the late Tertiary uplifts. In its

general extension the existing Susquehanna-St. Lawrence drainage divide has persisted since the Kittatinny (Cretaceous) peneplanation.

GLACIAL INVASIONS AND THEIR EFFECTS

The central southern plateau district was invaded at least twice by Pleistocene continental glaciers that originated in the Labrador center of dispersion. As the fronts were pressed southward they encountered the northward-facing escarpments developed by the durable formations. A lobe in advance

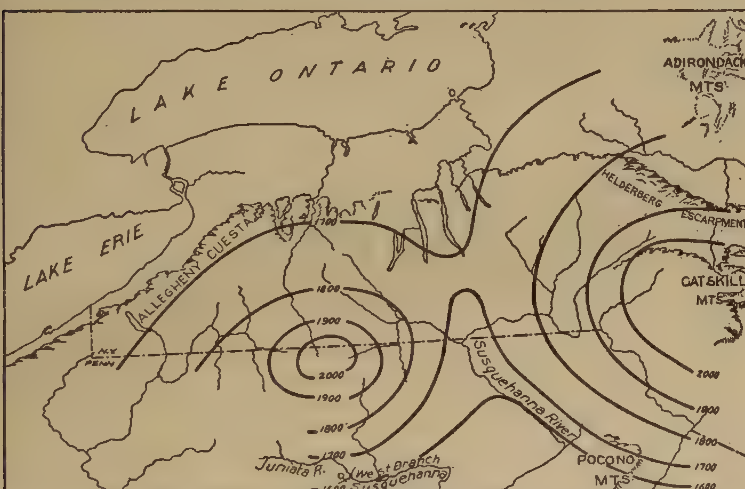

FIGURE 6.—Sketch map showing the upwarped surface of the Schooley peneplain. Contour interval 100 feet. After H. M. Fridley, Identification of erosion surfaces in south-central New York: Jour. Geology, vol. 37, p. 130, 1929

crowded into the narrowing V of the central embayment and eventually overrode the east-west divide in the south. The ice attained an altitude of at least 4,800 feet (1,463 meters) in the Adirondacks.

In the Catskills there are traces of glacial action at least as high as 3,900 feet (1,189 meters). Glacial striae occur on the summit of Elk Mountain, Pennsylvania, 2,700 feet (823 meters) above sea level. This mountain is about 50 miles (80 kilometers) south of Ithaca, New York, and Antevs (51, p. 64) calculates that the slope of the ice sheet in these latitudes was between 10 and 20 feet to the mile (1.9 and 3.8 meters to the kilometer). On the basis of this evidence it is quite certain that the ice of

the last advance ultimately attained a thickness of 3,000 feet (915 meters) in central New York. As the earlier glaciation is considered to have been more extensive the thickness of its ice was also probably greater.

At the maximum phase the general ice movement was undoubtedly a broad sweep southward. But the bottom ice moved in a diverse series of currents, governed originally by the preglacial topography, later very greatly by a modification of this topography, due to the erosion wrought by the ice itself. The results of such erosion were the creation of the basins of the major Finger Lakes and the opening of a remarkable series of through valleys. (See pl. 3, *A*.)

The phenomenon of the ice of a continental glacier advancing against drainage slopes into and across a major divide in a region of marked relief does not seem to have been duplicated elsewhere. The mass of the glacial ice that followed the northward sloping valleys was thrust into channels that narrowed progressively southward. In accordance with the law of adjusted cross sections, as formulated by Penck, the effect was to accommodate the excess of volume by increase in the rate of flow, until the effects of erosion magnified by the faster motion had deepened the passageways enough to provide the enlarged cross section necessary for an unimpeded, uniform forward motion of the glacier.

In this manner the north-south stream valleys were enlarged and deepened to become the rock basins of most of the Finger Lakes. These lakes are deepest in the narrowest parts of the preglacial valleys (not necessarily the divide sites). The east-west tributary valleys were also entered and followed by currents of the bottom ice. But as these valleys were smaller and were disposed athwart the general movement of the ice, such currents were less effective in erosion than those in the north-south valleys. Hence the east-west valleys suffered less modification of their preglacial form and little if any deepening from erosion by the ice except at their heads.

The overdeepening of the north-south valleys left the tributary east-west valleys hanging at their junctions with the main valleys—a relation that has permitted the postglacial development of innumerable waterfalls and gorges at the lower ends of the tributary valleys.

Where the basal currents in the ice, following the valley channels, overrode the preglacial east-west divide between the St. Lawrence and Susquehanna Rivers it so reduced divides (where in preglacial time a northward and a southward flowing stream had their headwaters directly opposed) as to make their earlier sites indeterminable by inspection. As a consequence of such

lowering, "through valleys" were created. These through valleys have truncated, steep, high walls; aggraded and in general level floors; and divides in swampy tracts. The reduction of divides is most conspicuous in the main north-south valleys but is not confined to them. It affected secondary divides as well as the main divide. The results of down cutting exhibit all degrees from small channels to great open troughs. (See pl. 3, *A*.)

Observers who argue that the ice was not competent to produce the results described probably have an exaggerated concept of the measure of differential erosion necessary. It is to be remembered that the ice was 3,000 feet (915 meters) or more thick. The groovings that are scenically so impressive are minor irregularities when they are considered in comparison with the mass of the glacial ice and the relief of the region as a whole. It is probable that in some of the narrower north-south valleys a large volume of drainage derived from the front of the advancing first ice sheets helped to erase preglacial divides. All northward-flowing streams then had their direction reversed, and consequently they overflowed and, probably aided by waterfall recession, cut down divides at their heads. During the retreat of the glaciers aggradation was dominant and generally obscured the sites of the divides cut down by water erosion.

In the recessional stages of the glaciation the major halts seem to have been to the north of divide lines. Furthermore, there was a marked degree of lobation, with long tongues of ice projecting down the larger north-south valleys.

North of a divide the ice rested massively in a basin; south of the divide it was only a thin wedge over the rock surface of the south slope. There was, accordingly, a distinct tendency to build up morainic deposits north of the divide sites—in places where a fixed position of the front, due to climatic equilibrium, could be most readily maintained. There was also a marked concentration of morainic débris in the valley channels, because the ice was deeper in them, because it moved more freely along such axes toward the ends of the projecting lobes, and because the water from melting of the ice was directed to the same points. The outflow waters transported vast quantities of glacial detritus to the ends of the lobes. It is entirely in keeping with this hypothesis that the massive moraines ascribed by Chamberlin to the "second glacial epoch" were accumulated in general at the valley-head sites on the north side of the major divide between the St. Lawrence and the Susquehanna. Such moraines are conspicuous features of the landscape, and where they have the form of a ridge they are referred to as "valley loops."

The configuration of the ice front during halts in the melting away of the glaciers promoted the recurrent development of a particular pattern of drainage at the border of the ice. (See pl. 4.) Such drainage was "forced" in that it could not pass the ice barrier; it was of large volume, it was loaded with sediment, and it tended to develop parallel to the channels of the east-west valleys. Where the ice blocked an east-west valley that sloped toward the ice front a lake was formed. A glacial lake of such origin had its overflow across the lowest saddle at the head of the lateral valley. The scour of the outlet current notched the saddle. Beyond the site of the overflow, the valley that carried the waters away from the ice tended to be cut back, by headwater erosion, through the outlet notches. The waters from the ice-dammed lakes filled such valleys to the equivalent of a great flood in the small cross sections of their headwater parts, and this great volume was augmented and given erosive effectiveness by sediment-laden drainage coming directly from the ice.

The diversion of the Chemung River at Elmira is of this origin. (See pl. 4.) The ice pressed against the north side of Hawes Hill to the height of its summit, and a short lobe extended southwestward into the Chemung Valley. This lobe served to pond drainage from the upper Chemung. The overflow of these ponded waters cut down the col between the two short streams that descended in opposite directions from the uplands. The ice barrier held its position long enough to permit the reduction of the col sufficiently to make it the course of the Chemung drainage after the ice withdrew. This, the original diversion, antedated the last ice advance. The fill of outwash gravel prevented the Chemung from resuming its preglacial course after the withdrawal of the Wisconsin ice.

In the Canisteo Valley similar factors operated to cause diversion of drainage in a more complicated pattern and on a larger scale. Prior to its retreat the ice blocked a northward-sloping valley that had its headwaters at Cameron. The overflow cut down the divide between this stream and one that flowed southeast, now the lower course of the Canisteo River. The drainage of the precursor of the upper Canisteo was augmented by the overflow waters from a lake ponded in the upper Genesee Valley. The Genesee overflow col was not cut deeply enough to remain a postglacial drainage course, but the divide that formerly separated what are now the upper and lower sections of the Canisteo was not reestablished.

Like the Chemung diversion, that of the Canisteo antedates the last ice invasion. Deposits from the ice of the last glaciation are present in all parts of these modified drainage courses.

After the ice had melted back from the position of its long halt on the line that in general followed the divide between the Susquehanna and St. Lawrence drainage basins, the front of the glacier ponded the drainage in the northward-sloping Finger Lake valleys and so initiated a complicated history of separate and connected glacial lakes. At each descending stage of the lake levels delta terraces were built at the mouths of tributary streams. In this section the most persistent level has been called the Lake Newberry stage. This stage had its overflow outlet at Horseheads, at an altitude of 900 feet (274 meters).

In the district around the heads of the larger Finger Lakes conclusive evidence of a long interglacial interval is afforded by the presence of buried and partly buried gorges. (See pl. 3, *B*.) Such interglacial gorges are the counterparts of the existing gorges that notch the lips of the tributary hanging valleys.

In some places these gorges are completely filled by the deposits of the last ice; elsewhere they intersect and form part of the postglacial gorge courses. It is hoped in the future to trace the filled sections by geophysical methods. Enough is known of their size in cross section, depth, and extension to indicate that the interglacial interval during which they were cut was considerably longer than postglacial time. If the North American and European glacial advances can be correlated, then the interglacial interval represented by the buried gorges was Mindel-Riss time. A deposit of much weathered, water-modified material of glacial origin found in one of these interglacial gorges at a site favorable for its preservation has been interpreted by the writer to be a portion of the drift of the earlier ice advances (56).

ITINERARY

Binghamton to Owego.—The rocks on the valley floor of the Susquehanna River belong to the Cayuta shale stage of the Chemung formation; those outcropping on the upper slopes and summits belong to the Wellsburg stage of the Chemung.

Glacial erosion of the hills by the last (Wisconsin) ice was feeble. The alternation of cliffs and moderate slopes of the valley sides is an inheritance from a preglacial or interglacial stage of river erosion, as glacial deposits are lodged close against the base of the steeper rock declivities. Postglacial erosion has cleared out very little of the fill left by the last ice retreat. The surface gravel is in the main glacial outwash veneered over with finer deposits of the modern flood plain. But the ice at the last phase of the glaciation appears to have lingered here as stagnant blocks for a considerable period. The gravel masses at the higher levels are moraine terraces, built against these ice blocks,

and commonly have a back slope toward the valley walls. There were also temporary pondings due to these ice blocks. It is probable that the greater part of the thickness of the valley fill represents accumulations in these temporary lakes. At Owego a well 101 feet (31 meters) deep failed to reach rock; other wells 50 to 150 feet (15 to 45 meters) deep have not found the rock floor. At Apalachin there are small eskers on the valley floor unaffected by postglacial erosion. Near Owego an uneroded mass of glacial drift, Hiawatha Island, still divides the river into two channels.

Owego to Candor.—The valleys of Owego and Catatonk Creeks are representative through valleys (p. 55). Two miles (3.2 kilometers) northwest of Owego a tributary to Owego Creek hangs 100 feet (30 meters) above the floor of the main valley. In view of the deep fill indicated by the well records from the Susquehanna Valley this difference in level is evidence of a marked overdeepening of valleys, to be attributed in part to glacial scour. Here the anomalous low-level north-south and east-west valley connections are to be noted. The narrower portion of the Catatonk Creek Valley, near Catatonk, evidently is the site of an old divide from which water went north and south.

In the quarries on Cemetery Hill, just north of Owego (altitude 1,010 to 1,020 feet or 308 to 311 meters) the second *Tropidoleptus* zone (lower Cayuta shale) is exposed. The fauna of the recurrent zone includes *Tropidoleptus carinatus*, *Delthyris mesicostalis*, *Phacops rana*, *Camarotoechia sappho*, *Spirifer marcyi*, *Cypricardella bellistriata*, and *Ambocoelia umbonata.* The Cayuta shale above and below contains a typical *Spirifer disjunctus* fauna.

Candor to Spencer.—The broad valley between Candor and Spencer, now followed by an insignificant stream, appears to have been a main preglacial channel. It follows also the strike of a low anticline. The rocks of the lower slope are Enfield shale; those of the summits, Chemung (Cayuta shale). In a small ravine half a mile (0.8 kilometer) east of Spencer, about 20 feet (6 meters) above the road level, there is an exposure of the upper Enfield shale and in it the first recurrent *Tropidoleptus* zone.

Spencer to West Danby.—Across the Susquehanna-St. Lawrence divide by way of the Spencer-Cayuga Inlet through valley. At Spencer the south end of a broad outwash plain is entered and crossed to the huge valley loop moraine (p. 55) on the Susquehanna-St. Lawrence divide about 1 mile (1.6 kilometers) north of North Spencer. South of Spencer Lake, a small morainic basin, a morainic deposit partly buried by out-

wash is passed. The moraine is best developed at the two ends, because of concentration of marginal drainage; at the center it is kamelike and low, with many kettles due to melting out of ice blocks. The steep north face of the moraine is a perfect ice-contact slope. A marginal morainal channel is seen parallel to the road on the west side of the moraine. The swamp south of the morainic ridge is due to ice-block melting after burial by outwash (pitted plain).

On the east side of the Cayuga Inlet valley, about 2 miles (3.2 kilometers) north of North Spencer, there is a site where erosion by drainage, reversed owing to the advance of the ice, led to the partial reduction of an earlier high divide (p. 55). As the cutting here was not continued to a condition of low gradient, this occurrence gives insight into the manner of the process that was elsewhere more completely effected.

When the ice front melted back from the stand at the moraine a glacial lake (Lake West Danby) was initiated. This lake had its overflow at 1,080 feet (329 meters) above sea level, at the east side of the moraine. The wide high shelf northeast of the moraine appears to be the shore flat of this lake. As the ice front melted back the area of the lake expanded. The secondary morainic arcs to the north of the main moraine have flat tops, suggesting limitations in deposit or erosion due to lake levels, and a thick cover of weathered lake clay indicative of the turbidity of the glacier-ponded waters.

The most striking feature in this section is the glacial oversteepening of the valley walls, with complete truncation of all spurs.

Headwater erosion of preglacial drainage working in from the north seems to have breached a rock divide that was earlier present in the now truncated section of the valley. This capture reversed the drainage of many small streams that had been tributary to the Susquehanna and caused a general rejuvenation of upland small stream valleys. The first ice advance widened and deepened the main north-south valley very greatly and created the through valley. The later ice advances followed the same grooves and freshened their glacial-trough outlines. (See pl. 3, *A*.) This glacial overdeepening brought about the hanging-valley condition of the upland tributary valleys.

A good exposure of the first recurrent *Tropidoleptus* zone (Enfield shale) with typical Portage fossils above and below it may be inspected a short distance up the crossroad toward the west in West Danby. About 150 feet (45 meters) above the recurrent zone the *Dalmanella danbyi* zone of the basal Chemung (Cayuta) appears.

West Danby to Enfield Falls.—The Cayuga Inlet Valley broadens a few miles north of West Danby, where postglacial erosion has dissected the morainic and lake deposits. The mixture of these materials (deposited under water) is observable in road and stream cuts.

Leaving the main road the excursion will climb the west slope of the Cayuga Inlet Valley on a road parallel to the course of Butternut Creek for an inspection of Enfield Gorge, where the Portage beds of the Devonian are encountered. The rocks of the lower slopes are the upper shale member of the Ithaca stage. The Butternut Creek Valley is entered at an interglacial section of its course. The postglacial gorge is at right angles to the drift-filled interglacial course, which swings around the hill to the north. The feature of the postglacial gorge is the perfection of the joint-plane guidance of the stream course. The lowermost portions of the gorge to about the top of Lucifer Falls are in rocks of the Ithaca stage of the Portage beds. The upper portion of the glen is in the Enfield shale. The top of the hill (altitude, 1,586 feet, or 483 meters) is capped by the Cayuta shale. On Connecticut Hill, to the southwest, the highest point in this part of the State (altitude 2,095 feet, or 638.5 meters), Chemung (Cayuta) fossils, including Dictyospongidae, are common.

The high Lucifer Falls, at the end of the upper gorge, are slightly upstream from the point where the interglacial gorge is again occupied by the stream. The Butternut Valley is thus doubly hanging. A wonderful prospect across the Cayuga Inlet Valley and its east side, with the glacially oversteepened slope 500 feet (152 meters) high extending to the level of 900 feet (274 meters), is had from the crest of the Lucifer Falls. There is an erosion channel contemporaneous with the sedimentation in the rock section just below the falls. Ripple marks here indicate that currents during the time of deposition came from the east (37, p. 531).

Enfield Falls to Ithaca.—Descending by the same road the route again follows the Cayuga Inlet Valley past the Buttermilk Falls, a hanging valley and hanging delta. The major part of the Buttermilk Falls is in the Ithaca stage. The upper Ithaca begins at about the top of the first cascade; Enfield shale caps the hill. The route is now along the east side of the Cayuga Inlet Valley. Just before entering the railway underpass about one-eighth of a mile (0.2 kilometer) down the road from the Buttermilk Falls the end of the interglacial Buttermilk Valley is seen on the left. Beyond the railway underpass, directly northwest across the flood plain at the head of Cayuga Lake, are the

remarkable series of terraces of the hanging deltas of Coy Glen. The oversteepened slope of the south end of Cayuga Lake is crossed by a circuitous route, over Sixmile Creek (Cayuga Street) where the black *Lingula*-bearing shales are well exposed, down State Street, Ithaca, to the foot of West Hill, where more lower Ithaca shale is exposed.

Ithaca to Taghanic Falls.—The road to Taghanic Falls is parallel to the west side of Cayuga Lake. At the Odd Fellows' Home there is a view of the Portage escarpment that forms the south side of the Fall Creek Valley and the hanging-valley condition of the several tributaries at the head of the Cayuga Valley. Above the escarpment the uniformity of the plateau level (1,700 to 1,800 feet, or 518 to 549 meters) marks the Tertiary peneplain beveled across southward-dipping rocks and flexures.

Across the lake at Portland Point is a low anticlinal fold made prominent by the Tully limestone. Farther south on the east side of the lake are Cayuga palisades in the Sherburne flagstones, a type example of regular jointing in sedimentary rocks.

Northwest along the road are minor morainic hummocks and morainal channels, which are slightly above the level of Lake Newberry (outlet at Horseheads, 900 feet, or 274 meters, above sea level). The upper Taghanic gorge is viewed from above.

At a quarry in Sherburne flagstones grotesque channel fillings or "burls" are seen on the south side. The limonitic band about halfway down the south side of the wall of the gorge marks the position of a bituminous coal seam half an inch (12 millimeters) thick.

The resistant Sherburne flagstone beds have determined the crest of the Taghanic Falls. The reentrant at the brink of the falls was made by the breaking out of a joint block about 1890. The vertical drop is due to rapid disintegration by weathering and undercutting of weak and block-jointed Genesee shales. Spray, local winds, and frost are important factors in the development of the amphitheater. The walls of the wide gorge below are kept steep by alternate lateral cutting of the stream. Small dikes of mica peridotite follow inclined joints in the Genesee shales. The Genesee here grades into the overlying Sherburne, and its top is marked by a zone of limy concretions, containing an abundance of *Styliolina fissurella*. This layer is thought to indicate the position of the limestone that delimits the Genesee in the western province. At this horizon have been found the oldest known American woody plants. The genus *Callixylon* found here has been studied by Dr. L. S. Petry and students of Cornell University (16, 17).

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Down the road alongside the gorge sections of hanging deltas are exposed. There is a small waterfall over Tully limestone. The recurrent layers of the Tully limestone yield an interesting fauna—*Hypothyridina* (*Hypothyris*) *cuboides*, *Phacops rana*, *Orthoceras* sp., and fragments of *Homalonotus*. The Tully limestone lies disconformably upon the Hamilton shale, about 3 feet (0.9 meter) of which is exposed. A better exposure of the Hamilton can be seen about a sixteenth of a mile (0.1 kilometer) south of Taghanic Falls on the Boulevard Road. Here on the north limb of the Portland Point anticline about 40 feet (12 meters) of the upper Moscow shale is exposed.

The route back to Ithaca along the shore follows close to the Tully limestone arch until the limestone sinks below the surface just north of the Glenwood Ravine, where black Genesee shale is exposed. On the west side of the road, just south of the entrance to the airport, a massive ledge of sandstone and the shales just above and below yield the *Reticularia laevis* fauna at the top of the Sherburne sandstone. This zone can be traced for several miles along both shores of the lake and is also present on Seneca Lake to the west.

Vicinity of Ithaca.—The Cascadilla Creek ravine has in its lower reaches the lowest shale member of the Ithaca with continuous exposure well into the upper beds. The zone of *Reticularia laevis* recurrence is at the waterfall south of the football crescent. A mica peridotite dike is exposed in the creek about 50 feet (15 meters) east of the College Avenue Bridge. The stairway up the south side of the gorge takes advantage of the space left by the weathering and erosion of the igneous material.

On Fall Creek the *Reticularia laevis* zone of the Sherburne is at water level at the foot of Ithaca Falls. The lowest shale member of the Ithaca appears in the vertical lower wall of the gorge; the middle Ithaca shale with basal recurrent Hamilton fauna occurs near the middle of the falls; the upper beds are found at the top of the ravine at the falls and are well exposed at the Sphinx Head fraternity building, at the north end of Stewart Avenue Bridge. The fauna of the upper Ithaca makes its appearance not far above the hydroelectric plant. Beneath and upstream from the Thurston Avenue Bridge at Triphammer Falls many blocks of a local limestone lens are found. These yield a large fauna of brachiopods and corals. The recurrent *Reticularia laevis* zone is in the creek bed at the bridge at Forest Home.

Cornell campus.—The Fall Creek gorge at the Thurston Avenue Bridge is postglacial. Beebe Lake above the bridge and the reentrant on the north side of the gorge below the bridge are sections of an interglacial gorge. (See pl. 3, *B*.)

The golf links are on a widespread deposit of lake clay of the glacial Lake Newberry level. Beyond the golf links there is a view of the Fall Creek delta at the Newberry level. Fall Creek was diverted to this northerly outlet by a stagnant ice block in its upper valley. On the rock slope below the Newberry delta there is a terrace with fine glacial groovings. From the descent of the road toward Esty's the postglacial delta of Salmon Creek at Myers is seen. At Esty Glen may be seen the contact of the Sherburne and the Genesee, marked by a massive pyritiferous sandstone layer above which black shale is repeated for several feet.

Portland Point.—In the faulted crest of one of the largest anticlines in this part of the State a cement company has opened a quarry in the Tully limestone. The southwest end of the quarry shows a small portion of the overthrust faulting. A large mica peridotite dike is exposed in the quarry.

The Tully limestone is overlain by the black Genesee shale and underlain by the upper members of the Hamilton formation. The stratigraphy of the Cayuga Lake region is as follows:

- Upper Devonian:
  - Portage beds—
    - Genesee shale stage.
    - Tully limestone stage.
- Middle Devonian:
  - Hamilton beds—
    - Moscow stage.
    - Ludlowville stage.
    - Skaneateles stage.
    - Marcellus stage.
  - Onondaga limestone.
- Lower Devonian:
  - Oriskany sandstone.
- Upper Silurian:
  - Manlius limestone.
  - Rondout water lime.
  - Cobleskill limestone.
  - Bertie water lime.
  - Camillus shale, including Fiddlers Green limestone and gypsum.

In Shurger Glen the upper Ludlowville member of the Hamilton is the floor rock and extends up the ravine walls to the limestone layer that caps the falls, the basal Moscow, above which occur the three shale members of the Moscow. The entire Hamilton section here exposed is fossiliferous.

Portland Point to Union Springs.—The route northward to Union Springs, near the foot of Cayuga Lake, passes over exposures lower and lower in the geologic column. The entire Hamilton section is exposed along the lake shore in the postglacial ravines. Between Aurora and Union Springs the Onondaga

limestone is reached, and just north of Union Springs the late Silurian crops out.

The oldest rocks in the Union Springs region are steel-gray limestones, well exposed in the railroad cut and creek bed at Cayuga Junction, 1 mile (1.6 kilometers) north of Union Springs. This limestone is probably referable to the Fiddlers Green limestone of the Syracuse region. The fauna is scanty; *Leperditia alta* and *Eurypterus remipes* are the most common forms. The beds dip to the south.

From the railroad cut the south branch of the railroad is followed south to the abandoned gypsum mill. Thence the route leads west to the flooded gypsum quarry, the base of which is on the Fiddlers Green limestone. The gypsum and black shale are about 35 feet (10.7 meters) thick and are probably an upper phase of the Camillus shale. They are overlain by the gray Bertie water lime, containing an *Orbiculoidea-Lingula* fauna.

Northeast of Cayuga Junction, at Cross Roads station, up the railroad track is an abandoned quarry with a good exposure of the upper Camillus shale member. The cut along the railroad just north of the quarry shows the overlying Bertie water lime, and on the east side of the track the Cobleskill limestone forms a miniature escarpment. It can be identified by the *Stromatopora* layers. The till-covered bench just to the east of the Cobleskill outcrop is made by the softer Rondout limestone. The many depressions and variable dip of the rocks in this region are due to the solution of the gypsum layer of the Camillus.

At Yawgers Woods the Oriskany sandstone crops out as a layer about 4 feet (1.2 meters) thick. The contact of the Oriskany and the Manlius is also well shown. The overlying Onondaga crops out in the pasture to the east. The Oriskany is replete with fossils, of which *Hipparionyx proximus*, *Rensselaeria ovoides*, *Meristella lata*, *Spirifer arenosus*, *Spirifer murchisoni* *Chonostrophia complanata*, *Megambonia*, *Diaphorostoma*, *Cyrtolites*, *Platyceras nodosum*, and *Orthoceras* are most abundant.

In a creek about a quarter of a mile (0.4 kilometer) south of Yawgers Woods there is an outcrop of the Manlius limestone, with the Onondaga lying upon it. Here there is no trace or only a slight trace of the Oriskany between the two formations. The place of contact is near the base of the small falls in the creek. At a quarry a quarter of a mile (0.4 kilometer) farther on there is an excellent exposure of the lower Manlius limestone.

Union Springs.—A good section is exposed in a ravine near the center of the village of Union Springs. The lower part is in the Rondout limestone, in which *Orthotetes interstriatus* and *Whitfieldella sulcata* are relatively common. The contact of the Manlius and Rondout is exposed about halfway up the ravine,

and the disconformable contact of the Onondaga limestone and Manlius is near the top of the section. (See pl. 7, *A*.) The Manlius here contains a layer of *Stromatopora* near the top. The Onondaga contains an abundance of chert.

Frontenac Island, a few hundred yards offshore from Union Springs, owes its existence to the Cobleskill limestone that caps it and to a local syncline between it and the land. Glacial erosion removed the weaker Rondout beds that occupied the syncline. Cobleskill fossils are abundant on Frontenac Island.

In a quarry about 1 mile (1.6 kilometers) south of Union Springs there is an excellent exposure of Onondaga limestone overlain by the lowest members of the Hamilton beds—the Marcellus black shale with Cherry Valley limestone above. The total thickness of the Onondaga in this region is about 100 feet (30 meters). The dip in this quarry is purely local and may be due to solution or to buckling from increase in volume due to anhydrite changing into gypsum.

Just across the road from the south quarry is a quarry in the Onondaga. The floor of this quarry yields many fossils, among which is *Odontocephalus selenurus*.

Union Springs to Ithaca.—The return to Ithaca is made by way of Venice Center and Genoa. On the grade down Esty Hill glacial grooving appears along the east wall. At the foot of Esty Hill, at McKinney's station, is the Twin Glens locality in the lower Portage beds. The *Reticularia laevis* zone at the top of the Sherburne sandstone is about 20 feet (6 meters) above lake level. A short distance north along the railroad track unusually fine jointing in the Sherburne sandstone is seen.

Ithaca to Watkins Glen.—The route to Watkins Glen goes through Mecklenburg. At about 1,000 feet (305 meters) above sea level on the western slope of Cayuga Valley there is a faint beach development of the high-level lake that overflowed through the Sixmile Valley and was the predecessor of Lake Newberry. From this viewpoint the hanging valleys of Fall, Cascadilla, and Sixmile Creeks are discernible. Beyond Mecklenburg the road ascends nearly to the level of the Schooley (Tertiary) peneplain and then descends over an ice-steepened slope into an old northeastward-trending valley. This valley was occupied by a lateral projection from the main ice lobe in the Cayuga Valley when the Wisconsin ice was withdrawing from this region. Where the road descends into the valley 2 miles (3.2 kilometers) southwest of Reynoldsville this lateral projection built a very conspicuous valley loop moraine, 100 feet (30 meters) high, with the concave ice-contact face toward the north and east. About 1 mile (1.6 kilometers) farther southwest a similar lateral projection from the large Seneca Valley lobe

built great morainic masses with ice-contact faces toward the west and south.

South from Bennettsburg is Texas Hollow, a perfect example of a through valley. When the glacier was retreating ice tongues pushed into it from both ends. When the Bennettsburg and Reynoldsville moraines were built Texas Hollow may have been the course of a very considerable volume of drainage from melting ice. The fact that its north end flares markedly indicates that it was a main channel of ice motion at higher stages of the glacier.

From Burdett the route descends diagonally across the over-steepened slope of the Seneca Lake Valley to the level of the delta fill at Watkins. Seneca Lake has a maximum depth of 618 feet (188 meters), and its surface is 444 feet (135 meters) above sea level.

Watkins Glen is a postglacial gorge cut into the Ithaca and Enfield shale members of the Portage. It is especially notable for its development by pothole scour and grooved channels. An interglacial gorge parallel to the existing gorge on the south is filled with deltaic and other deposits.

The lower shale member (Cashaqua) of the Sherburne stage crops out in the lower portion of Watkins Glen, and above it a limestone member (Parrish) appears. The upper black shale member (Rhinestreet) is almost indistinguishable; the middle portion of the glen is in the undifferentiated Ithaca (Hatch) formation. The uppermost reaches of the glen, beyond the railroad bridge, are in the lowest sandstone membei (Grimes) of the Enfield stage.

Watkins Glen to Penn Yan.—The road to Dundee cuts across the eastern edge of the Altay-Wayne gas field, where wells 1,700 to 1,900 feet (518 to 579 meters) deep reach the Oriskany formation. At Penn Yan the outlet of Keuka Lake and the interglacial-postglacial gorge are crossed. The steep descent from an altitude of 700 feet (213 meters) at Keuka Lake to 400 feet (122 meters) at Seneca Lake, together with clear water and constant volume, give opportunity for hydroelectric power development. The two arms of Keuka Lake were the preglacial sites of two stream valleys.

Penn Yan to Bath.—From Penn Yan the route runs close to the west side of the west branch of Keuka Lake to Hammondsport. The former divide between the northward and southward flowing streams was at the mouth of Wagener Glen, just north of Gulicksville, on the west shore of Keuka Lake. Here is seen the glacially eroded slope of Bluff Point on the opposite side of the lake. At Wagener Glen there is a good section of the

Portage beds. The thrust from the glacial current coming in from the east arm of Keuka Lake greatly steepened first the west side, then the east side of the main stem of the Keuka Valley at Hammondsport. The delta at the head of the lake and the opportunity to land on the lake caused Hammondsport to be selected as the site for the early development of the aviation industry, particularly the hydroplane branch, by Glenn Curtiss. The typical Chemung pelecypod fauna may be collected at road cuts between Risingville and Hornell.

South of Hammondsport the road ascends the slope of a great valley-head moraine (45), at whose summit the Susquehanna-St. Lawrence divide is again crossed.

Bath to Hornell.—The Cohocton Valley at Bath is a northwest-southeast through valley between the St. Lawrence and Susquehanna drainage basins that was given its present expression through a combination of erosion by waters from glacier melting and fills of glaciofluvial and morainic deposits. (See pl. 4.) Preglacially there appears to have been a divide northwest of Bath. The front of the ice forced all drainage southwestward by preventing escape toward the northwest.

The route from Bath leads southeast to the mouth of Babcock Hollow. Opposite this hollow there is a wide flat whose altitude (1,150 feet or 350 meters) corresponds with that of the flat north of Bath and which is probably a remnant of once continuous fill between these points. Babcock Hollow is the site of a glacial overflow. Waters temporarily prevented, by a lobe of the ice farther southeast, from following the Cohocton Valley here followed a devious course through the hills and emerged into the Cohocton Valley again at Campbell.

From Risingville the route goes over the hills to the Canisteo Valley at Cameron. (See pl. 4.) The Canisteo Valley is entered close to the preglacial divide between northwestward and southeastward flowing streams. As in the Cohocton Valley, forced drainage along the ice front eliminated this divide and developed a long gorge. Reduction of the base-level of this drainage through such erosion revived all the tributary streams, so that these now enter the modern Canisteo River from the north and south through rejuvenated valleys. These tributary valleys, however, unlike those of the valleys overdeepened by glacial erosion, are not hanging but enter at grade. This difference is significant evidence of the unlike nature and effects of glacial and river deepening of valleys. Also the winding course of the Canisteo gorge is in contrast to the straight and truncated slopes of the glacially overdeepened north-south through valleys.

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HORNELL TO EAST AURORA

By C. A. Hartnagel

CANISTEO VALLEY

Leaving Hornell the route continues up the Canisteo Valley. The steep slopes rise to a series of flat-topped hills 700 to 800 feet (213 to 244 meters) above the river valley. These hilltops are the remnants of the Allegheny Plateau. The rock formation is lower Chemung, abundantly fossiliferous in the glens about Hornell.

North from Hornell the valley, which had almost gorgelike proportions at Adrian, gradually expands, and before Arkport is reached the flat bottom is more than 1 mile (1.6 kilometers) wide. It is evident that this valley in preglacial time carried a northward-flowing stream which had its headwaters near Adrian. In glacial time waters were impounded in this valley to form Hornell Lake. A delta at Webbs, on the west side of the valley, was formed in this lake. At Arkport the Canisteo River enters the valley at grade through the steep hills at the west. Beyond this point for several miles the valley is without streams of any size. At the hamlet of Moraine, on the west side of the valley, Canaseraga Creek enters the valley through a break in the hills. In glacial time this valley gave outlet to some of the higher lakes of the Genesee Valley to the west. The large delta just west of Moraine was built in Hornell Lake. Morainic material on the west side was piled against an ice lobe that lingered in the valley. Canaseraga Creek after entering the broad valley takes a northerly course along the west side through a narrow channel some 300 feet (91 meters) lower than the valley plain followed by the road. Three miles (4.8 kilometers) north of Moraine the level open valley is piled high with glacial deposits, and the highway ascends the hill along the east side over morainic materials and delta deposits laid down in Hornell Lake by Stony Brook.

Descending the hill from the top of the moraine we come to Stony Brook Glen, with walls 200 to 240 feet (61 to 73 meters) high consisting of Portage (Gardeau) flags and shales. Some of the thicker beds seen near the top represent the beginning of Nunda sandstone sedimentation. The part of the glen up to the railroad bridge has a length of 3,600 feet (1,097 meters), and three small waterfalls occur in the interval. Mud-flow structure and beach and ripple marks in the Portage beds can be observed in the glen to good advantage, and plant remains may be found.

The Gardeau beds consist of light bluish-gray sandstones and flags separated by beds of blue, olive-green, or black shales.

The entire formation has a thickness of about 400 feet (122 meters). Fossils are rare. Brachiopods of the Ithaca fauna occur in some of the sandstones; pelecypods and cephalopods of the Naples fauna in the soft shales. The light bluish-gray Nunda sandstone has some intercalated beds of shale, in which there are a few representatives of the Gardeau fauna. Westward the fossils are very rare and the Nunda formation barely reaches Lake Erie; eastward it carries a Chemung fauna (High Point sandstone). The maximum thickness of this formation is 125 to 215 feet (38 to 66 meters).

CANASERAGA VALLEY

From Dansville north the valley of Canaseraga Creek carries a northward-flowing stream. The valley is deeply drift filled; in the vicinity of Dansville a well to a depth of 450 feet (137 meters) failed to reach bedrock. The glacial waters held in this valley were connected with those of the Genesee Valley, known as Dansville Lake. The outlet was at Burns, through the Canisteo Valley. The route down the Canaseraga Valley follows the west side and opposite Groveland makes a left turn to follow a southwest direction toward Portageville, approximately along the probable course of the preglacial Genesee River, now masked by glacial materials. The postglacial or present Genesee and Canaseraga Creek now join farther north, in the vicinity of Mount Morris.

At Tuscarora the highway crosses Keshequa Creek, the type locality for the Cashaqua shales of the Portage formation. At Nunda is the type section for the Nunda sandstone, which is better seen, however, at Portageville. From that point the route leads directly to the Genesee gorge in Letchworth Park.

LETCHWORTH PARK

The Genesee River in its northward flow from Pennsylvania crosses in descending order outcrops of the entire Devonian system except the lower division, which is not present in this area, and farther north the river crosses the entire Silurian section. In four places in its course the Genesee Valley shrinks to a narrow steep-walled ravine or canyon—two at Portage, a third near Mount Morris ("High Banks"), and a fourth at Rochester. These deep canyons represent very recent or postglacial work of the river where it has been forced from its old valley into a new path, those at Portage and Mount Morris representing a single diversion.

The upper part of the Portage district has been set aside as a State park. The rocks in this splendid gorge section were

early studied by James Hall, State geologist of New York, from 1837 to 1898. A bronze tablet erected in Letchworth Park to commemorate the work of Hall carries these words: "This gorge exhibits the typical expression of Hall's Portage group, whose rocks carry an assemblage of organic remains most widely diffused throughout the world."

The two canyons in the Portage district are the Portage Canyon and Portage High Banks. The Portage Canyon begins near the village of Portageville and holds three cataracts. The upper falls, formed on the Nunda sandstone, have a height of 71 feet (21.6 meters). The middle falls and lower falls are formed on the Gardeau flags and shales, the former with a drop of 107 feet (32.6 meters), the latter of 70 feet (21.3 meters). The lower falls, about 2 miles (3.2 kilometers) below the middle falls, are reached by steps and a path from the highway. Here are shown the position of an older falls over Table Rock, giant ripple marks, the joint flume below the falls with a tremendous pothole, and the river course at a former higher level (notch in cliff).

The canyon at Portage High Banks below the lower falls extends for about 3 miles (4.8 kilometers) with no cataracts, though the steep rocky slope of the river bed produces rapids. This canyon, with a depth of 500 feet (152 meters), is deeper than the Portage Canyon proper, which has a depth of 200 to 300 feet (61 to 91 meters). In passing north through Letchworth Park, stops will be made at different points to view this gorge. The Portage High Banks should not be confused with the Mount Morris High Banks, the third canyon of the region. The stretch of the three canyons and the two intervening open valleys covers a distance of 14.5 miles (23.3 kilometers) in a direct line (18 miles (29 kilometers) measured along the stream) from Portageville to Mount Morris.

LETCHWORTH PARK TO EAST AURORA

After crossing the valley of Wolf Creek a left turn is made toward Castile and on to Silver Springs, where the evaporating works of the Worcester Salt Co. are located. At this place a bed of rock salt 100 feet (30 meters) thick is encountered 2,200 feet (671 meters) from the surface. The first step in the extraction of the salt is to drill a hole to the bed and put down a double pipe. The outer pipe reaches the top of the salt, and the inner pipe goes to the bottom. Fresh water forced down the outer tube dissolves the salt, and the brine thus made rises under pressure in the inner tube and is conveyed to settling vats. As the cavities in the rock salt enlarge, adjacent wells may become

connected. When this takes place one or more wells may be used to carry fresh water, and the others serve as brine wells. Various modifications in methods of obtaining the brine are employed, such as using the wells alternately for brine and for fresh water. From the settling tanks, where the less soluble impurities are removed, the brine goes to the evaporating plant, which is equipped with multiple-stage vacuum pans. Rapid crystallization of the salt is effected, resulting in a large yield of fine-grained salt.

At Silver Springs the headwaters of Wolf Creek are left behind, and the divide is crossed to the valley of Oatka Creek. At Warsaw the route ascends a steep hill, passing a good outcrop of Gardeau shales. Thence the way is almost directly west over Portage and Chemung formations. The higher hills form the northern margin of the Allegheny Plateau, and after crossing several valleys such as those of Tonawanda Creek at Varysburg and Buffalo Creek at Wales Center, the route leads to East Aurora, which lies in the Lake Erie drainage basin.

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EAST AURORA TO NIAGARA FALLS

By John T. Sanford

The route between East Aurora and Niagara Falls traverses a glaciated country underlain by sedimentary rocks ranging from late Silurian to late Devonian in age. The Lower Devonian is missing, the Upper Devonian resting disconformably on rock of late Silurian age. The strata dip gently southward at an angle of about 1°. Here and there the monotony of the structure is broken by minor folds or faults. The country has been subjected to erosion since late Paleozoic time, and the protruding edges of the harder strata cause the surface to rise southward in a series of gentle steps. Lake Erie and Lake Ontario occupy valleys cut by preglacial streams in the soft intervening shales. The details of the topography are due to glaciation and postglacial erosion.

Buffalo and Niagara Falls are located in a farming country in which the principal crops are fruit and vegetables. Owing to its location at the east end of Lake Erie and the western terminus of the Barge Canal and the store of electrical energy available at Niagara Falls the area is an important industrial center. Buffalo is the second largest inland port in the United States, Chicago being the largest.

EAST AURORA TO HAMBURG

About 1 mile (1.6 kilometers) from East Aurora, along the road to Orchard Park, Cazenovia Creek has since glacial time exposed a part of the Rhinestreet shale, of Upper Devonian (Portage) age. Here the characteristic jointing (prominent in two directions) can be seen. The Rhinestreet consists of about 185 feet (56.4 meters) of black fissile shale commonly weathering to a rusty color. In the upper part of the formation dark-gray beds are present. There are numerous limy concretions, many of which are very large, 6 feet (1.83 meters) or more in their longest dimension. Many of them are septaria, and fossils have been found in some of them. A large *Dinichthys* from one of these concretions may be seen at the Buffalo Museum of Science.

The road parallels the stream valley for some distance, and in a few places small tributary streams have exposed a few feet of the Rhinestreet shale near the roadside. Fragments of this shale can be seen in the roadside ditches.

In the outskirts of the town of Orchard Park, 7 miles (11.2 kilometers) from East Aurora to the right of the road, is a cemetery on a ridge that marks the shore line of glacial Lake Whittlesey. Just beyond Orchard Park minor undulations in the topography indicate the morainal character of the glacial material. This is a portion of a terminal moraine that passes through the towns of Hamburg, Aurora, and Orchard Park and continues on to the east. Several miles out of Orchard Park, where the route turns to the left along Abbott Road, the country is notably flat, as might be expected in an area that was occupied by glacial Lakes Warren and Whittlesey. Between Armor and Hamburg the road closely follows the shore line of Lake Warren, which, however, is not easily seen here.

HAMBURG TO EIGHTEENMILE CREEK, LAKE ROAD

Between Hamburg and the Lake Road the route follows the postglacial gorge of Eighteenmile Creek much of the way and is nowhere far from it. The country rock is still the Rhinestreet shale, which can be seen in the creek banks in several places.

The country is rather flat here also, partly because it formed the bottom of the two glacial lakes.

Toward Lake Erie the creek has cut down through the Rhinestreet shale, and some of the underlying formations are exposed, though the route is too far from the stream for them to be seen until it reaches Lake Road, where there will be an opportunity to examine a typical Middle Devonian section, with a few feet of the Upper Devonian at the top. The section is as follows:

Portage:
- West River shale.
- Genundewa limestone.

Hamilton:
- Moscow shale.
- Ludlowville shale (with Tichenor limestone member).

The base of the outcrop is covered in places with talus, which contains excellent fossils weathered out of higher beds, thus affording an opportunity to collect the fauna of the Moscow shale, which is out of reach. The Ludlowville shale is the only formation that is readily accessible. The soft gray shales are calcareous and contain numerous limy concretions, some of them at definite horizons. At one of these horizons, several feet below the Tichenor, the concretions are fairly persistent, having been found in the same part of the section at other localities in Erie County. In places marcasite concretions are also plentiful, and many of them contain fossils. As a whole the formation is extremely fossiliferous, and its outcrops afford some of the best collecting in the region. *Athyris spiriferoides* is very abundant in the Ludlowville shale at a horizon about 9 feet (2.7 meters) below the Tichenor limestone. Many specimens will be found overgrown with delicate Bryozoa and *Aulopora* corals. Spirifers (*Spirifer mucronatus* most abundant) are also numerous, as are various other forms (*Chonetes lepidus*, *Ambocoelia umbonata*, *Pholidops hamiltoniae*). *Leiorhynchus laura* and the characteristic Hamilton pelecypod *Modiomorpha subalata* are common in the lower beds. The Ludlowville shale is about 90 feet (27.4 meters) thick. Near the base are several persistent limestone bands, sometimes referred to as the "trilobite beds," remarkable for numerous specimens of the trilobite *Phacops rana*.

The Tichenor member, approximately 1½ feet (0.46 meter) thick, is a thin band of limestone, in places crinoidal. Marcasite is also plentiful, and much of the rock is rust-colored from the oxidation of this mineral. The limestone carries an abundant Hamilton fauna, but good specimens are sometimes difficult to obtain. Corals and bryozoans are numerous, and among

the corals *Favosites hamiltoniae* predominates. The large heads of *Favosites* are of especial note. Brachiopods occur (*Rhipidomella*, *Stropheodonta*, *Vitulina pustulosa*, *Tropidoleptus carinatus*). *Spirifer sculptilis* is among the most abundant fossils of the formation. One of the most striking species is a large pelecypod, *Plethomytilus oviformis*. Trilobites (*Phacops rana*), gastropods (*Diaphorostoma lineatum*), and other forms are occasionally found. The abundance and character of the life during Tichenor time indicate reef conditions.

At Eighteenmile Creek the Moscow consists of 17 feet (5.2 meters) of gray fossiliferous shale, which becomes thicker to the east. Its base is well marked by the Tichenor limestone, and its top by the Genundewa limestone, from which it is separated by a disconformity. The typical Tully limestone and Genesee shale, which are found between the Moscow shale and Genundewa limestone farther east, are missing. In the Moscow shale a few feet above the Tichenor limestone is a coral layer with species mostly of the genera *Heliophyllum*, *Cystiphyllum*, and *Zaphrentis*. The small *Streptelasma rectum* occurs above and below this layer, and in places *Favosites hamiltoniae* is common. Among the brachiopods are *Spirifer tullius*, *S. consobrinus*, *S. audaculus*, *Ambocoelia umbonata*, *Leiorhynchus laura*, *Athyris spiriferoides*, *Chonetes mucronatus*, *Atrypa reticularis*, *A. aspera*, and *Pholidops hamiltoniae*. Pelecypods (*Actinopteria decussata*), a few crinoids, and the trilobite *Phacops rana* are found.

The Genundewa limestone is a thin dark-brown concretionary limestone made up largely of shells of the minute pteropod *Styliolina fissurella*. The lower part at Eighteenmile Creek differs from the remainder and is known as the conodont bed, from the large numbers of conodonts which it contains.

Above the Genundewa limestone in full section is 8½ feet (2.6 meters) of West River shale. This formation consists of rather thin bedded and for the most part black shales containing but few fossils, although a small pelecypod (*Pterochaenia fragilis*) and the pteropod *Styliolina fissurella* are fairly numerous in places.

EIGHTEENMILE CREEK TO BUFFALO

The route turns northward near the shore of Lake Erie toward Buffalo. The Hamilton beds are intermittently exposed along the lake shore, a low cliff having been formed by wave erosion since glacial time.

About 8 miles (12.8 kilometers) beyond Eighteenmile Creek the plant of the Bessemer Portland Cement Co. is seen on the left. In Lackawanna is one of the plants of the Bethlehem Steel Co. On the left after entering the Buffalo city limits are

the Lehigh Cement Co.'s plant, the Canadian Port Terminal grain elevators, the Minnesota Atlantic Co.'s freight terminal, and the Ford plant. As the route enters farther into the city it passes numerous coal docks, flour mills, and grain elevators. Buffalo is the largest flour-milling center in the eastern United States. The Buffalo Museum of Science is in Humboldt Park.

BUFFALO TO NIAGARA FALLS

A stop will be made in Buffalo at the quarry of the Buffalo Cement Co., from which came the splendid collection of eurypterids of the Bertie water lime to be seen at the museum. In this quarry the unconformity between the Silurian and Middle Devonian is exposed. Above the unconformity is the Onondaga limestone; below it is the Bullhead argillaceous limestone (Akron), resting upon the Bertie water lime, both late Silurian.

The contact between the Bertie and the overlying Bullhead is gradational, and it is difficult to determine just how much of the section is Bertie. The water lime, however, seems to be present in the quarry floor and in some places for a foot or so above it. The Bertie is about 50 feet (15 meters) thick, and the beds weather to a buff color. Fossils are rare on the whole, and the fauna consists principally of eurypterids. The Bullhead, which is correlated with the Cobleskill (65), [7] is an impure dolomite about 8 feet (2.4 meters) thick. The cup coral *Cyathophyllum hydraulicum* and the brachiopod *Spirifer eriensis* are the characteristic fossils of the Bullhead limestone. Marcasite is scattered through the rock.

The top of the Bullhead is an uneven erosion surface exhibiting stream channels. In many places there is a thin layer of shale between this surface and the overlying Onondaga, and here and there a lens of sandstone. Sandstone dikes have also been described from this formation (63, 65). Inasmuch as the Onondaga limestone is the overlying formation, the sand has been considered to be of Oriskany age.

The basal beds of the Onondaga limestone have filled the irregularities in the surface of the later Silurian rocks and thus exhibit a contorted appearance in places. Chert nodules abound in some of the beds of this dark bluish-gray limestone, which is about 160 feet (48.8 meters) thick in this area. Fossils are plentiful at various horizons; at many localities the basal bed is a coralline limestone, whose thickness varies from place to place.

Leaving Buffalo the route passes northward through Kenmore toward Niagara Falls. The town of Tonawanda occupies a

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[7] Numbers in parentheses refer to bibliography, p. 78.

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delta built by the Niagara River in glacial Lake Tonawanda, and practically the entire route between Tonawanda and Niagara Falls lies over silt deposited in this lake.

On the outskirts of the former town of LaSalle (now part of the city of Niagara Falls) a boulder and flagpole on the lawn of a white farmhouse (at the left) mark the spot where the French explorer LaSalle, in 1679, built the *Griffin*, the first vessel built by white men for use on the Great Lakes.

As the city of Niagara Falls is approached the road passes near the works of the Hooker Electro-Chemical Co. on the right and the Niagara Alkali Co. on the left. A short distance beyond, on the left, may be seen the plants of the Roessler-Hasslacher Chemical Co., the Mathieson Alkali Co., the Carborundum Co., and the Acheson Graphite Co. Not far beyond these are the upper power houses of the Niagara Falls Power Co., and a short distance farther the International Paper Co's., mill. The route now enters the oldest residential section of the city, in which is situated (at the right) the original plant of the Shredded Wheat Co., and continues to Prospect Point, overlooking the falls.

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NIAGARA FALLS AND GORGE

By Frank Bursley Taylor

To geologists, the chief interest of Niagara Falls (pl. 5, *A*) centers in the story of its origin and the process by which the falls have made the great gorge. The history of the gorge is revealed chiefly in two ways—(1) in certain characteristics that mark it as the work of a great vertical cataract, and (2) in changes of volume of the river, indicated not only by certain features in the gorge but also indirectly by correlation with the history of the four Great Lakes that lie above. Since Niagara began making the postglacial gorge several changes have occurred

in the direction of overflow of the upper three lakes, showing two periods during which their combined waters, equal to 85 per cent of the whole volume of the present Niagara River, found its way to the sea by other routes, leaving to Niagara the discharge of Lake Erie alone. Naturally, these large changes of volume had a marked effect on the gorge-making power of the cataract. The main factors that caused these changes were the retreat of the last great ice sheet north-northeastward across the lake basins and the differential uplift of northern lands after the removal of the weight of the ice. It is chiefly out of the interplay of these two causes that the remarkable history of Niagara Falls and the gorge has arisen.

GENERAL RELATIONS IN THE NIAGARA DISTRICT

Niagara district during time of the last ice sheet.—During the maximum extent of the last or Wisconsin ice sheet, the Niagara district lay under about 3,000 feet (914 meters) of ice and was near the axis of the main ice stream that moved southwestward through the basins of Lakes Ontario and Erie. The district was continuously under the burden of the ice sheet, not only during the entire time that the front of the ice was retreating from a point 10 miles (16 kilometers) north of Cincinnati but during an equally long time, probably, in the advancing phase.

As the ice front retreated northeastward in the basin of Lake Erie impounded glacial waters gathered in front of it and covered the lower ground as fast as the ice withdrew. For a relatively short time after the ice had uncovered the present site of Niagara Falls and the gorge, the waters of the later lakes (glacial Lakes Wayne, Warren, and Lundy) covered this district to a depth of 100 to 150 feet (30 to 45 meters). At this stage the ice front had retreated to a position probably about at the present shore of Lake Ontario north of Lewiston. The new eastward outlet past Rome, New York, soon drew the waters in the Lake Ontario Basin down to a level considerably lower than the present level of Lake Erie, inaugurating the flow of the Niagara River and completing the separation of Lake Erie from Lake Ontario. Niagara Falls then began the work of making the gorge at the escarpment south of Lewiston.

Geomorphic development.—The Niagara district lies between Lake Erie and Lake Ontario, in the midst of a region that has the geomorphic and geologic characteristics of an eroded ancient coastal plain. After the deposition of the Paleozoic sediments the region as a whole was raised out of the sea and appears to have been a land surface ever since. In so great a length of time the region has, of course, been extensively modified by subaerial

and stream erosion, but it does not appear to have been affected by marine denudation. The highlands of Canada are the oldland, and the remaining beds of the ancient coastal plain dip gently southward from it. Some of these beds are soft and others hard. The softer beds have been reduced to lowlands; the harder beds remain as uplands of relatively low relief. Thus, through the effects of erosion, the ancient coastal plain has become what is called a belted plain, composed of a series of narrow, nearly flat plains separated by northward-facing escarpments, like a flight of steps descending toward the north, but with the tread of each step slanting gently backward toward the south. This gives the escarpments or upland belts the form of a cuesta.

South of the oldland lies the Ontario lowland, and the basins of Lake Ontario and Georgian Bay are excavated in it. To the south stands the Niagara cuesta, with its steep escarpment facing northward over the Ontario lowland and Lake Ontario. In this district the gentle back slope of the plain holds the shallow Tonawanda-Chippewa Valley which was the site of a temporary lake known as Lake Tonawanda. South of Lake Erie and extending eastward through New York stands the much higher Allegheny escarpment. Another lower cuesta lies between the Niagara and the Allegheny—the Onondaga escarpment, formed by the outcropping ledges of the Onondaga limestone. The Erie lowland lies south of it and holds the bed of Lake Erie.

Hard and soft strata in the Niagara Gorge.—The ancient belted plain, with its east-west parallel features of relief, was the ground over which the Niagara River began to flow as soon as the glacial lake waters were drawn off. Into this plain the cataract has sawed the great canyon. North of Lewiston there was no capping hard layer and hence no vertical fall, and the banks are composed of soft red shale and are relatively low. The gorge begins at the escarpment south of Lewiston, and from this place to the present main cataract the arrangement of the strata has generally favored the existence of a vertical fall.

The hard, massive bed of the Lockport dolomite forms the capping layer throughout the gorge and increases in thickness from less than 20 feet (6 meters) near Lewiston to about 80 feet (24 meters) at the Horseshoe Fall, 130 feet (40 meters) at the first cascade above the fall, and about 200 feet (61 meters) in well borings farther south. The lower beds consist of the Clinton limestone, with the Thorold sandstone close below and the Whirlpool sandstone still lower; these beds are hard but relatively thin. The rest of the strata are mainly soft shales, with a few thin sandy, harder beds. In general the strata appear to the eye to be horizontal, but they dip toward the south almost

uniformly 20 feet to the mile (3.8 meters to the kilometer). Near the mouth of the gorge the dip for some distance is slightly greater. All the strata decline southward from the mouth of the gorge to the Horseshoe Fall 130 to 140 feet (40 to 43 meters).

The first thick hard layer below the Lockport is the Clinton limestone, which is about 20 feet (6 meters) thick and forms a distinct bench along the sides of the gorge at some places. Only 12 feet (3.6 meters) of this limestone show above water at the Horseshoe Fall. At Foster Flats the Clinton forms a prominent bench, and many of the great fallen blocks rest upon it.

The only other noteworthy hard layer is the Whirlpool sandstone, which is on the average about 25 feet (7.6 meters) thick. At the mouth of the gorge the top of this sandstone is 142 feet (43 meters) above Lake Ontario; at Foster Flats, about 75 feet (23 meters). It forms the floor of the flats and of Niagara Glen, and its bottom is at the water's edge at the head of Foster Rapids. At the Whirlpool it forms a bench a few feet above the water and is most accessible on the east side below Whirlpool Point. Farther south it passes beneath the level of the river. At the Whirlpool the surface is about 47 feet (14 meters) above Lake Ontario, so that the sandstone declines about 80 feet (24 meters) from the mouth of the gorge to this place. On the west side opposite the American Fall, a shelf submerged 90 to 100 feet (27 to 30 meters) is presumed to be this sandstone, showing a decline of 50 to 60 feet (15 to 18 meters) from the Whirlpool to the falls, for the river surface at the base of the falls is about 100 feet (30 meters) above Lake Ontario.

The process of gorge making.—The gorge is being lengthened by boring at the base of the falls, where the heavy mass of falling water strikes at the end of its vertical descent. The softer strata are slowly worn away by the impact of the water itself, but the hard capping layer is removed chiefly by undermining until it falls away in huge blocks that drop into the cauldron at the foot of the falls and become highly efficient tools for grinding away the shale. Many of the blocks are spun around in the violent currents in the same way that pestle stones are spun in the making of potholes. The limestone is much harder than the shale, and although the spinning slowly wears away the blocks, it removes the shale at a much faster rate.

At times when the falls had large volume and full height the thinner hard layers were easily bored through and removed, but when the height of the falls was in effect reduced, as it was for a time in the older part of the gorge, or where the water sheet passing over the brink became relatively thin, as it did in several places, parts of these beds were not wholly removed and now form benches or terraces. It is thought that when the

volume of the river was relatively small, as it appears to have been in one part of the postglacial gorge and probably in another shorter part, these layers were not both bored through by one vertical plunge but in all probability formed separate cataracts. This was probably the condition in most of the gorge north of Niagara University.

GENERAL RELATIONS OF THE GREAT LAKES TO THE NIAGARA RIVER

Except for a few small streams that enter the Niagara River above the falls, all the water in the river comes from the Great Lakes above. During two periods the discharge of Lake Erie alone passed over the falls; at other times the great cataract has carried the full discharge of the upper four lakes. During one period the full four-lake discharge was considerably increased on account of the relatively large amount of melt water that flowed directly from the extensive tributary ice barrier on the north. But this condition was temporary. Serving as great storage reservoirs, the lakes acted as equalizers of flow, and on this account the Niagara River is characterized by a steadiness of volume found in few other rivers. It has a slight seasonal variation of volume amounting to about 2 feet (0.61 meter), and it has a variation amounting to 3 or 4 feet (0.91 to 1.21 meters) over a period that corresponds roughly to the 11-year wet and dry cycles that seem to vary with the frequency of sun spots. Considerably larger variations are caused by cyclonic storms on Lake Erie and by ice jams in the river itself. A heavy southwester has been known to raise the water level at Buffalo nearly 8 feet (2.4 meters), and a severe northeaster has lowered it nearly 6 feet (1.8 meters). The great ice jam of February, 1909, held the water back so that the American Fall went almost entirely dry, and people walked across near the brink. But these variations are of very short duration. The Niagara River knows no such thing as the great seasonal floods that affect rivers like the Ohio and the Mississippi. The ordinary variations are much too short and too small to produce measurable effects in the dimensions of the gorge. Certain parts are relatively wide and deep, and others are relatively narrow and shallow. These sections range in length from 2,000 feet (610 meters) to 2¼ miles (3.6 kilometers) and are therefore much too large and require too long a time in their making to be attributed to minor variations.

It might be thought that lines of weakness in the rocks have been an effective cause of variation in the dimensions of the gorge, but this is surely not true in any large degree. The geologic structure is remarkably uniform throughout. Except

for the thickening of the capping limestone from Lewiston to the falls, no lines of weakness or variations of structure are known that would produce a measurable effect. Finally, the importance of all such factors dwindles to almost nothing in comparison with another variable element that has been beyond doubt the chief cause of variations in the dimensions of the gorge—namely, changes in the volume of the Niagara River.

An observer beginning at the mouth of the gorge and noting its changing dimensions in going toward the falls, especially its changes in depth and in its width at the top of the cliffs, can easily distinguish at least five major divisions, together with certain features that suggest other minor divisions less clearly. Here is recorded the most complex phase of Niagara history, for not all of the gorge occupied by the present river has been carved out of the rock by its own action in postglacial time. Certain parts were made by a much older river closely resembling the present stream in volume. These parts appear to have been made in the interglacial epoch preceding the last or Wisconsin ice sheet. The gorge made at that time closely resembles the present gorge, but it was completely overridden by the last ice sheet and filled partly with lake sediments, but mainly with glacial drift. Later these soft deposits were quickly removed by the modern river. The older or pre-Wisconsin parts of the gorge begin with the Whirlpool Basin and extend to a point a short distance south of the cantilever railroad bridge. The problems raised by these sections are not yet fully settled.

OUTLINE OF THE GREAT LAKES HISTORY SINCE THE BEGINNING OF NIAGARA FALLS

The relation of the Great Lakes to Niagara Falls has been so intimate that a brief summary of their history seems necessary in this place. Since the falls began to make the gorge at Lewiston the Great Lakes have passed through five stages of change (see figs. 7, 8), each stage with a different outlet from that of the stages immediately preceding and following it, and the water discharged through the Niagara River has undergone a large change of volume with each change of outlet. The first stage of Lake Algonquin was limited to the south half of the Lake Huron Basin. The other two stages and also the Nipissing Great Lakes were limited to the basins of Lakes Superior, Michigan, and Huron. None of these four stages included the basin of Lake Erie. The five stages were as follows:

1. Early Lake Algonquin.
2. Lake Algonquin, Kirkfield stage.
3. Lake Algonquin, Port Huron stage.
4. The Nipissing Great Lakes.
5. The present or post-Nipissing Great Lakes.

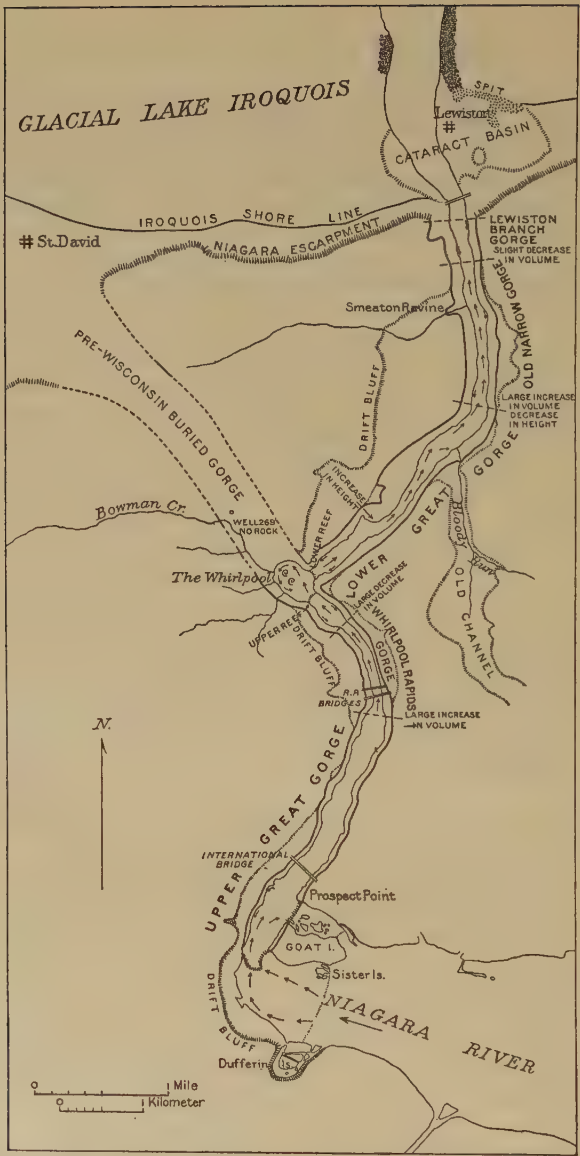

FIGURE 7.—Sketch map of Niagara Gorge showing the five named divisions of the gorge and changes in volume of the river and height of falls corresponding to the five lake stages shown in Figure 8, which determined their character. Lewiston Branch Gorge, cut during the first lake stage; small volume. Old Narrow Gorge, second lake stage; small volume. Lower Great Gorge, third lake stage; large volume. Whirlpool Rapids Gorge, fourth lake stage; small volume. Upper Great Gorge, fifth lake stage; full volume of upper four lakes. From U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), fig. 14, 1913

Four of the Great Lakes—Superior, Michigan, Huron, and Erie—lie above the Niagara River and discharge their waters through it at the present time. But during two periods in the past the first three discharged their whole overflow by another route, not passing through the Niagara River.

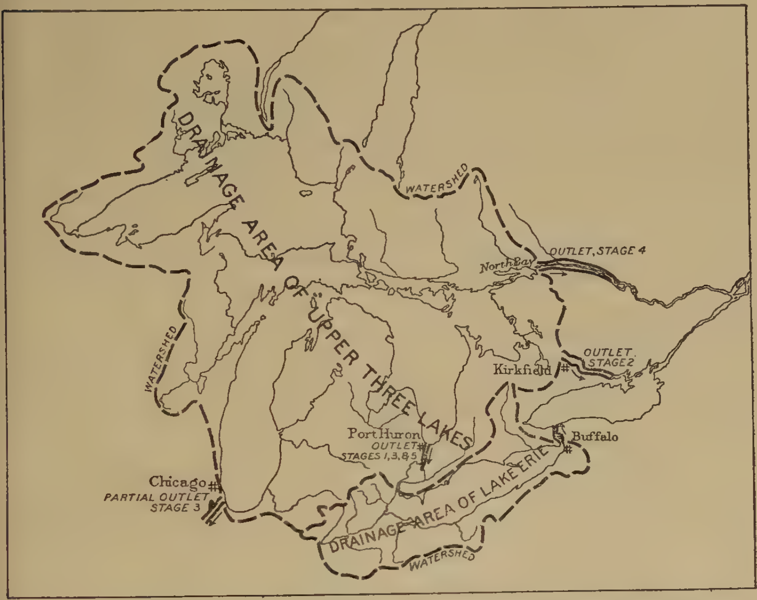

FIGURE 8.—Sketch map showing drainage areas tributary to the Niagara River, the volume of discharge through the river during five lake stages, and the various outlets of the upper three Great Lakes during these stages. Stage 1, early Lake Algonquin; large volume of discharge divided between Niagara River and four other spillways over Niagara escarpment. Stage 2, Kirkfield stage of Lake Algonquin; small volume through Niagara River; large discharge through outlet at Kirkfield. Stage 3, Port Huron-Chicago stage of Lake Algonquin; large volume through Niagara River; small discharge through outlet at Chicago. Stage 4, Nipissing Great Lakes; small volume through Niagara River; large discharge through outlet at North Bay. Stage 5, present Great Lakes; full discharge of the upper four lakes through Niagara River. From U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), fig. 12, 1913

1. Early Lake Algonquin occupied the south half of the Lake Huron Basin. The outlet was southward through the St. Clair and Detroit Rivers to Lake Erie, and the discharge through the Niagara River at that time was probably nearly if not quite as large as it is now, but it was relatively short lived. Only a fraction of it—perhaps one quarter— fell over the escarpment at

Lewiston; the rest formed four smaller temporary cataracts within a distance of 50 miles (80 kilometers) to the east—at Lockport, Gasport, Medina, and Holley.

2. Lake Algonquin at the Kirkfield stage occupied parts of the basins of Lake Superior and Huron. Its outlet at Kirkfield, Ontario, was opened by the northeastward retreat of the ice front. During this stage the Niagara River had only the discharge of Lake Erie.

3. During the Kirkfield stage the lake waters gradually expanded toward the northeast by following the retreating ice front, but finally the pronounced and widespread uplift of northern lands closed the outlet at Kirkfield and sent the discharge to Port Huron. In the first half of the Port Huron stage there appears to have been a considerable temporary discharge at Chicago in addition to that at Port Huron. Toward the end of this stage the ice sheet had dwindled to so small a frontage that its contribution of water became relatively small and finally ceased.

4. The Nipissing Great Lakes stage was initiated by the final withdrawal of the last obstructing remnant of the ice sheet from the Ottawa Valley and the opening of an eastward outlet at North Bay, Ontario. Thus, for the second time Niagara Falls was left with only the discharge of Lake Erie.

5. Continued uplift of northern lands gradually raised the outlet at North Bay, Ontario, to a higher level than that at Port Huron and sent the overflow of the upper three lakes back to the St. Clair River and thence to Lake Erie and the Niagara River. In the transition both outlets were active at once, but this delicate balance was probably of relatively short duration. The old outlet at North Bay is now 104 feet (31.7 meters) higher than the Nipissing beach at Port Huron. Except for the recent artificial diversions at Chicago and for the Erie and Welland Canals, the Niagara River now carries the entire discharge of the upper four lakes.

Depression of northern lands during the time of the ice sheet is commonly attributed to elastic deformation under the weight of the ice, and the uplifting movement during and after the retreat of the ice to elastic resilience or rebound as the weight of the ice was removed. In the early stages of glacial retreat uplift appears to have been spasmodic, this phase continuing about to the end of Lake Algonquin, when the movement became slower and more steady down to the present time.

In the older parts of the gorge, extending from its mouth up to the head of Foster Flats, the varying level of the waters in the Lake Ontario Basin had a pronounced effect on gorge making, for at first the waters stood somewhat below the present lake

level, but later they stood 125 feet (38 meters) higher than the present level. This depth of water backed up into the gorge had the effect of reducing the height of the falls temporarily. This effect is seen in the wide, shallow section between the Niagara University and the head of Foster Flats.

CORRELATIVE CHARACTERS AND SECTIONS IN THE GORGE

The order of lake stages as given above and the large variations which they caused in the volume of the Niagara River suggest that correlative features and sections should be found in the gorge. Four or five major divisions are discernible at a glance. These are indicated mainly by striking differences of width and depth—differences not due to differences of geologic structure. There are also certain minor features which have special significance.

Lake Tonawanda and the Lewiston Branch Gorge.—Early Lake Algonquin came into existence when the Niagara, Detroit, and St. Clair Rivers began to flow and established Lake Erie as an independent lake. On the Tonawanda lowland the Niagara River encountered a long, shallow basin, the Tonawanda-Chippewa Valley (73).[8] In this depression it formed a temporary lake (fig. 9), which covered the low ground around the city of Niagara Falls and extended eastward about 45 miles (72 kilometers). Its width ranged from 1 to 7 miles (1.6 to 11.3 kilometers). This lake had five outlets, each forming a cataract where it poured over the Niagara escarpment (68). The falls at Lewiston and Lockport were larger than that at Gasport, and those at Medina and Holley were still smaller. The erosion accomplished by the several outlets leads to the belief that the Lewiston outlet carried about 25 per cent of the whole river, or, roughly, five times as much water as that carried by the American Fall before the recent large diversions for power, and about two-fifths more than the discharge of Lake Erie alone.

The gorge made by the Lewiston outlet is not so clearly distinguishable from the section next south of it as might be desired, but its average top width of about 1,400 feet (427 meters) is about 100 feet (30 meters) greater and its cliff lines are also more irregular. These characters extend for about 2,000 feet (610 meters) south from the mouth of the gorge and are believed to mark the extent of the Lewiston Branch Gorge.

Old Narrow Gorge.—Next south of the Lewiston Branch Gorge is a section which is notable for the straightness of its cliff lines and the evenness of its top width, which averages about 1,300 feet (396 meters). It is relatively narrow at the water surface, and

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[8] Numbers in parentheses refer to bibliography, p. 103.

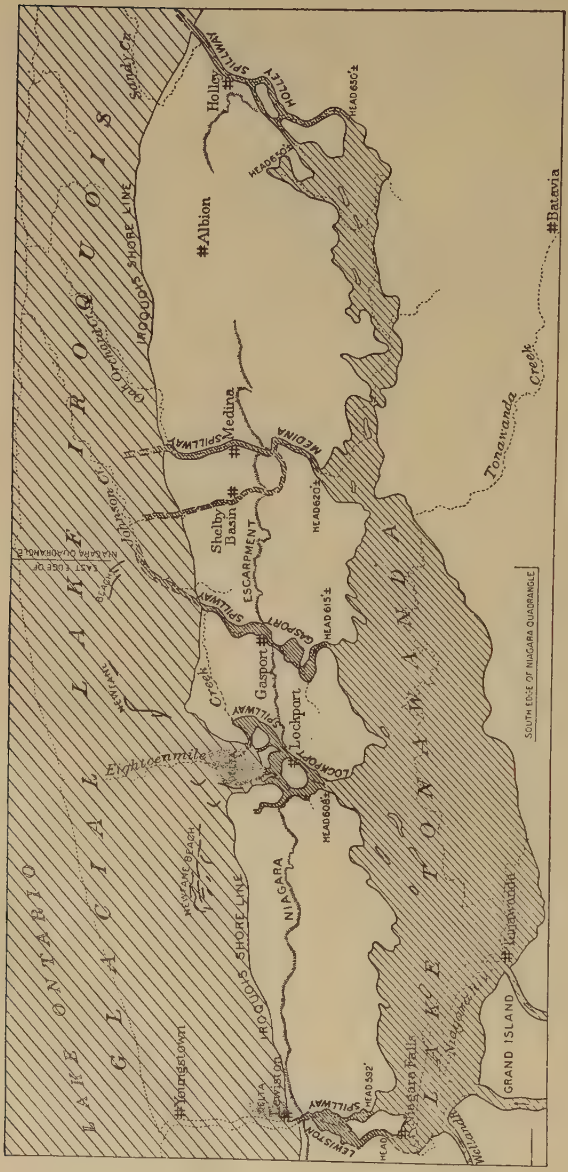

FIGURE 9.—Sketch map of Lake Tonawanda and spillways from it to glacial Lake Iroquois. The lower or early stage of Lake Iroquois, into which the spillways emptied, is partly indicated by the Newfane beach. The shore line of Lake Tonawanda is approximate, as it has been accurately determined in only a few places. Present altitude above sea level of heads of spillways is given. From U. S. Geol. Survey Geol. Atlas, Niagara folio (No. 190), fig. 10, 1913

its depth averages less than 100 feet (30 meters). It is a little more than 1 mile (1.6 kilometers) long, and its talus slopes are wider than in the newer sections. This is due partly to a greater thickness of exposed soft rock (Queenston shale) and a thinner capping hard layer, but also partly to longer exposure to weathering. Recent differential uplift of the land in the north-northeast has backed the water up in the western part of Lake Ontario, in the lower part of the Niagara River, and also to some extent in this section of the gorge, partly covering the talus slopes and making the river surface wider and the water deeper and less swift than formerly.

This gorge section is correlative with the Kirkfield stage of Lake Algonquin, when the upper three lakes discharged eastward through the Trent Valley in Ontario. It seems certain, therefore, that this section was made by a relatively small cataract—by Niagara when it carried the discharge of Lake Erie alone. Thus, although originally made relatively narrow and shallow, this section has been largely widened at the top by a relatively long period of weathering.

The Lower Great Gorge.—At the university the gorge widens perceptibly (see pl. 5, *B*) and the greater width continues to a point within about 2,000 feet (610 meters) of the Whirlpool. To the head of Foster Rapids this section is relatively shallow and the water is swift and somewhat turbulent, but above that it is deep and quiet. From the university to a point about 1,200 feet (366 meters) above the head of Foster Rapids the top width between the cliffs averages more than 1,600 feet (488 meters), and the widest place is 1,825 feet (556 meters).

This section is correlative with the Port Huron stage of Lake Algonquin, for the same uplift of northern lands that raised Kirkfield and stopped the overflow of the upper three lakes at that place sent the water back to Port Huron, where it had discharged during the time of early Lake Algonquin. The extra width of this part of the gorge is due partly to the augmented volume of the river, in consequence of the large amount of melt water which came directly from the extensive ice front that stretched across Lakes Superior and Huron, and partly to the wide, flat rock floor that caused the water above the falls to spread to unusual width, reducing its depth on the brink and making the falls wider and slower in their recession. This last-named condition appears to have caused the formation of Wintergreen Terrace and the associated lower rock terraces of Niagara Glen. During the early part of this time glacial Lake Iroquois stood 100 to 125 feet (30 to 38 meters) higher than Lake Ontario now stands, and the backwater in the gorge reduced the cataract's boring power; hence the shallow part of the section.

When the falls were a short distance above Foster Rapids, they appear to have suddenly regained their power to bore deeply. This event appears to be correlative with the opening of a lower outlet for glacial Lake Iroquois around the north side of the Adirondack Mountains and the abandonment of its earlier outlet at Rome, New York.

Ancient gorge sections.—The basin of the Whirlpool was not carved out of the rock by the present or postglacial Niagara, but by the cataract of a much earlier river of either preglacial or interglacial age. After it was made, the Whirlpool Basin was overridden and filled with drift by the last or Wisconsin ice sheet. The postglacial river had only to wash out these soft sediments and when it had breached the rock wall on the east side of the basin it did this work quickly. The northwest wall is composed entirely of drift from side to side and extends to an unknown depth below the water. As seen at the Whirlpool, the buried cliff lines of the ancient gorge run parallel toward the northwest. South of St. David and about 2½ miles (4 kilometers) northwest of the Whirlpool there is a break in the front of the great escarpment, where rocky strata are absent and the gap is filled with drift. (See fig. 10.) This marks the mouth of the ancient buried gorge. The widening on the west side of the mouth of the gorge south of St. David is due to glacial action. The gorge is of interglacial rather than preglacial age.

Formerly (72) the buried gorge was thought to end at the southeast side of the Whirlpool Basin, and the making of the Eddy Basin and the gorge of the Whirlpool Rapids was attributed to the present or postglacial river—the Eddy Basin at full volume, the narrow gorge with the smaller discharge from Lake Erie alone. But facts recently brought to light indicate a different history.

Nineteen exploratory borings were made by the Michigan Central Railroad Co. in 1899 in preparation for the building of the Cantilever Bridge, but the very significant results obtained did not become known to geologists for several years. The borings show unmistakably the existence of a wide, deep rock gorge under the Cantilever Bridge and extending probably 500 to 700 feet (152 to 213 meters) farther south. This Cantilever Gorge, as it may be called, is filled with clayey material and many large blocks of limestone and sandstone, showing that, like the Whirlpool Basin, it was overridden and filled with drift by the Wisconsin ice sheet; and the inference seems plain that the Eddy Basin and the gorge of the Whirlpool Rapids are, in all probability, of pre-Wisconsin age and were buried in the same way.

If the postglacial Niagara has had to remove only drift from the Whirlpool to the Cantilever Gorge, inclusive, the time estimate for the making of the whole gorge will have to be revised and the estimate reduced from a mean of 25,000 years, more or less, as formerly given, to a mean of 18,000 to 20,000 years.

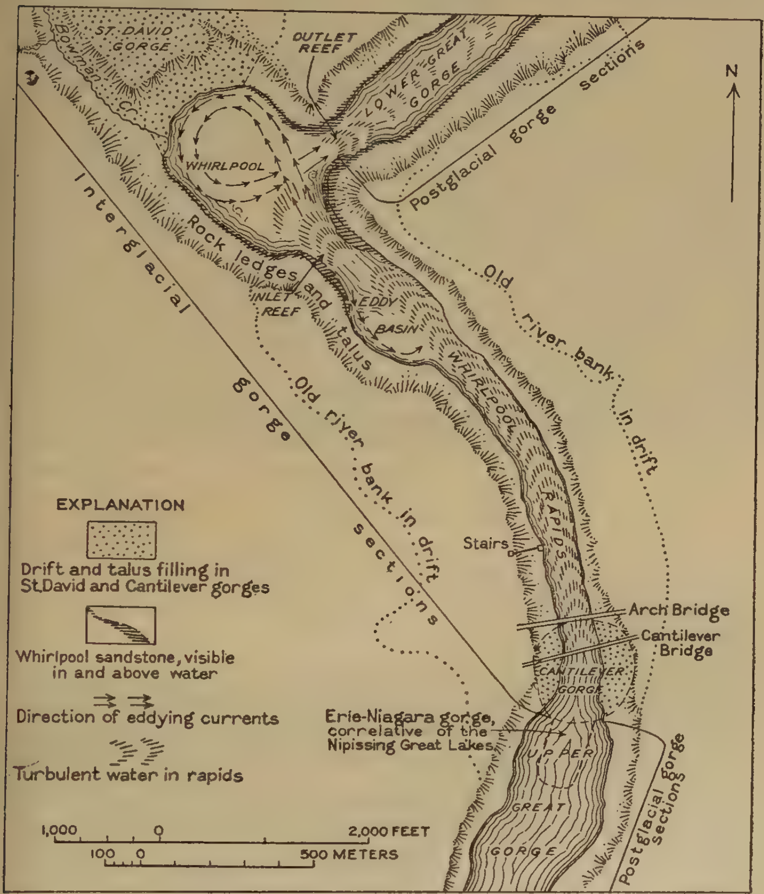

FIGURE 10.—Drift and talus filling in St. David and Cantilever Gorges

Under the steel arch bridge, which is only 300 to 400 feet (91 to 122 meters) north of the Cantilever Bridge, the cliff is steeper and is composed of rocky strata in places to an undetermined depth below the water on both sides. At the Cantilever Bridge the slope is less steep, no rock in place is exposed below the capping

hard layer at the top in each side, and the borings show a great depth of filling. So great a contrast between gorge cross sections so close together is remarkable.[9] The evidence seems to indicate clearly that the ancient gorge was made by an interglacial cataract in every way like the present falls of Niagara—a vertical fall having substantially the same volume of water.

Probable gorge correlatives of the Nipissing Great Lakes.—During the first stage of the Nipissing Great Lakes, when the whole discharge of the upper three lakes passed eastward at North Bay, Ontario, and thence down the Mattawa and Ottawa Rivers to the sea, Niagara Falls could have had only the discharge of Lake Erie, amounting to about 15 per cent of the present four-lake full-volume river. This inference seems sound and unavoidable; and yet in the present gorge we see no section that can be certainly identified as the correlative of the Nipissing stage of the lakes. The gorge made by the relatively small cataract of this stage must have been relatively narrow and shallow, and it must have been made after the making of the Lower Great Gorge and before the making of the Upper Great Gorge, which is discussed below.[10]

If the cleaning out of the drift in the interglacial gorge sections (from the Whirlpool Basin to the Cantilever Gorge inclusive) could be supposed to have required a length of time that would accord with the probable duration of the Nipissing Great Lakes, the problem of correlation with gorge history

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[9] In 1907 Spencer (73) made first geologic mention of the "borings" at the Cantilever Bridge, but in his text and cuts he described and showed only one bore hole. Spencer's observations on the significance of the borings did not then receive the attention they deserved. Recently this evidence has been more fully discussed by Johnston (71), whose paper was reviewed by the present writer (74).

[10] Dr. Ernst Antevs (67a) has recently suggested a different interpretation of a part of the gorge. The present author suggested the making of a shallow, narrow gorge extending southward from the south side of the Cantilever Gorge (74) as the probable correlative of the Nipissing stage of the lakes. But if such a gorge was actually made it must later have been obliterated by the return of the full-volume cataract. From 2,000 to 2,500 years was allotted for the making of this Erie-Niagara section—a rather short allowance. It may have taken two or three times this long. Antevs did not see this possibility but instead put the work of the small-volume Nipissing cataract back to a narrow, shallow section in the Lower Great Gorge and called it the Niagara Glen Gorge. He apparently overlooked the fact that all the major characteristics of the Lower Great Gorge are harmoniously explained in the interpretations set forth in the Niagara folio (72) and that the Lower Great Gorge includes other parts both north and south of his Niagara Glen Gorge which are then left without satisfactory explanation. Although the author's explanation of the gorge correlative of the Nipissing lake stage is based mainly on theoretical grounds, an extension of the time allotted in the making of the Erie-Niagara gorge as set forth in the author's recent paper (74, fig. 10) is much preferred to the radical revision of the correlations in the Lower Great Gorge, as suggested by Dr. Antevs.

A. AERIAL VIEW OF NIAGARA FALLS
Photograph copyright by M. J. Washburn; used by permission.

B. VIEW DOWN NIAGARA GORGE FROM DEVILS HOLE
Courtesy of State Reservation at Niagara.

A. AMERICAN FALL BEFORE ROCK SLIDE
Courtesy of State Reservation at Niagara.

B. AMERICAN FALL AFTER ROCK SLIDE
Courtesy of State Reservation at Niagara.

would be easy. But this supposition seems quite improbable, although, with the small-volume cataract, the time involved may count as a measurable factor. It seems almost certain, however, that in addition to the clearing out of the ancient sections, a short new section of gorge, narrow, shallow, and perhaps 600 to 700 feet (182 to 213 meters) long, was made by the small cataract, beginning at the middle of the south wall of the Cantilever Gorge. Then, when the North Bay outlet was finally closed by northern uplift and the whole four-lake discharge returned to the Niagara, the great river would overwhelm the small new gorge, pouring in along its sides, deepening and widening it, and finally obliterating it entirely. On the basis of this interpretation, a clearly marked correlative in the gorge would not be expected. This hypothetical small gorge, extending south from the buried and only partly reexcavated Cantilever Gorge, is shown in Figure 7.

Upper Great Gorge.—Whatever the details of gorge history may have been during the time of the Nipissing Great Lakes, a new stage of lake history was begun when the outlet at North Bay, Ontario, ceased to function and the overflow for the upper three lakes shifted to Port Huron. Here began the present or post-Nipissing stage, and with the falls constantly at full four-lake volume, the gorge which they made is relatively wide and deep. The average top width north of the American Fall is 1,350 feet (411 meters), with a least width of 1,025 feet (312 meters) at Swift Drift Point. Its greatest width is opposite the American Fall and is 1,600 feet (488 meters). Width greater than the average continues to the south side of Goat Island. The deepest sounding is near the southwest corner of Goat Island, with a depth of 192 feet (59 meters) (73). The average central depth north of the American Fall is about 160 feet (48.8 meters); south of this fall, 100 to 120 feet (30.5 to 36.6 meters).

It was formerly supposed that all of this section was made by the postglacial river, but allowance must be made for the ancient Cantilever Gorge, buried by the last ice sheet and now only partly reexcavated. Allowing for the Cantilever Gorge at least 500 to 700 feet (152 to 213 meters), or say one-eighth of a mile, or 660 feet (201 meters), takes off this much of the north end of the wide gorge and shortens correspondingly the distance and time of recession of the postglacial falls. This section is the correlative of the present stage of the Great Lakes and is still in the making. It has been made by the present river with 100 per cent volume, but in consequence of the large diversions of water for canals and power, it is now being extended with slightly reduced volume. The amount of diverted water has increased at

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a relatively rapid rate in the last 20 or 30 years, but while this increase has produced visible low-water effects on all the shallow parts of both cataracts and in the rapids above the falls, it has not yet produced a measurable effect on gorge making.

Crossing the line of the gorge in this section is an east-west ridge of heavy limestone, Johnson Ridge, renamed by Spencer (73, p. 156) Lyell Ridge. It is part of the capping hard layer, and its crest was near the narrowest part of the section, close to Swift Drift and Hubbard Points. On the ridge the altitude of the brink of the fall was considerably higher than now, and it continued high for about three-fourths of a mile (1.2 kilometers), or to the vicinity of Hubbard Point. The bed of the river above the falls was then of such an altitude that the water surface south of the ridge was close to 585 feet (178 meters) above sea level; whereas the water surface a little back of the brink of the Horseshoe Fall is now a trifle above 510 feet (155.4 meters). The early place of the river surface is shown by the wave-cut shore line of Lake Tonawanda in the southern part of the city of Niagara Falls, New York. Extensive gravel bars occur in the southwestern part of the city and on Goat Island. They originally covered most of the space now occupied by the rapids above the American Fall and extended a considerable distance to the west over the site of the present gorge, including a part that extended downstream toward Hubbard Point and another part that extended south at least a few hundreds of feet beyond the present south side of Goat Island. Until the falls cut through the top of the ridge the river flowed over this site with a gentle current well suited to the development of gravel bars. The upper limit of the gravel is close to the contour of 560 feet (171 meters), or about 25 feet (7.6 meters) below the shore line of Lake Tonawanda. Probably the level of the river had fallen 5 or 10 feet (1.5 or 3 meters) from the Lake Tonawanda shore line before the falls reached the col on the ridge. Thus, the gravel probably lay on the bottom of the gently flowing river during the entire time taken by the falls to cut out the gorge from Lewiston to the Whirlpool, to clear out the ancient sections, and to cut back from the Cantilever Gorge to the col. In this long period of time they formed an ideal habitat for certain mollusks, and their remains, softened by decay, have been found in great numbers in the gravel pits, especially on Goat Island. With continued recession, the brink of the falls began to shift slowly down the southward slope of the ridge, and as it moved to lower positions the height of the falls grew relatively less, descending in all about 65 feet (20 meters) and bringing into existence the rapids both north and south of Goat Island.

A heavy ledge of Lockport limestone running south from the east end of Goat Island forms the Upper Cascade at the head of the rapids and acts as a dam to hold the upper river in its gentle flow. The relatively high level of the rock floor at the east end of Goat Island limited the amount of water entering the rapids above the American Fall and made them shallow. Before some of the recent diversions (before those established since 1911), the American Fall carried 4.85 per cent of the whole volume of the river (75, p. 13). The ledge dips gently to the south, causing the deeper channel to pass near the Canadian shore.

The greater width of the gorge opposite the American Fall and Goat Island is due to the flat, nearly level rock floor in this stretch and to the ease with which the drift was washed away at the sides. This made a wide crest line and relatively shallow water on the brink. The river in this stretch is shallower on its west side. This and other extra wide parts of the gorge, except the Whirlpool Basin, mean a slower rate of recession for the postglacial cataract in these parts. On the other hand, the contraction in width near Hubbard and Swift Drift Points is due to the fact that the capping hard layer was there nearly 50 feet (15 meters) thicker than it is now at the Horseshoe Fall or has been at any time during the last mile (1.6 kilometers) or more of recession. This also tended to reduce the rate of gorge making.

AMERICAN FALL

After cutting through the col near Hubbard Point, the falls were soon lowered 15 or 20 feet (4.6 to 6.1 meters), and powerful currents scoured out part of the gravel where now are the rapids above the falls. Of two scouring currents, the main one passed south of Goat Island and turned north around its west end. The smaller stream passed north of it and is now the American Rapids. Less than half a mile (0.8 kilometer) south of the col the retreating falls reached the foot of the southward slope of Lyell Ridge. They were then only a few feet higher than the present Horseshoe Fall and have continued to the present time at nearly the same height. At first the American Fall constituted the eastern part of the great cataract. Not until the main fall had receded nearly 1,000 feet (305 meters) farther did the lesser cataract become separated from it. Since that time the main fall has continued receding and has left the American Fall pouring in a thin sheet over the side wall. There it has remained essentially unchanged through the 600 or 700 years that have passed since the separation.

Gilbert (68) made the rate of recession of this fall 0.2 foot (0.06 meter) a year; Spencer (73), 0.6 foot (0.18 meter). The first instrumental survey of the crest line was made by James Hall in 1842. Eight later surveys have been made, but all, including the latest (Niagara Reservation Commission, 1931; see fig. 11), when compared with that of 1842, fail to show any certain, measurable recession. In fact, in several places the lines determined by the later surveys stand farther forward than that of 1842, showing that the margin of error in the surveys is greater than the amount of recession in those places.

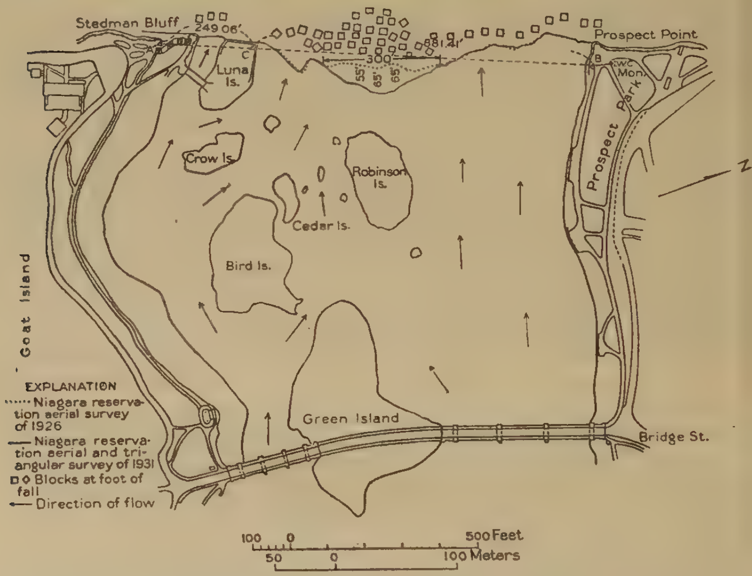

FIGURE 11.—Map showing contour of American Fall after collapse of January 17, 1931. By State Reservation at Niagara

Great rock slides from the central part of the American Fal occurred on January 17 and 18, 1931, making a relatively larg new recess in the crest line. This fall is 915 feet (279 meters wide, omitting Luna Island, and 168 feet (51 meters) high. Fig ure 11 shows the crest line and the location of the rock slides The new break is 300 feet (91 meters) wide and in its centra part 65 feet (20 meters) deep horizontally at the top. Plat 6, *A*, taken from Stedman Bluff before the slides, may be com pared with Plate 6, *B*, taken from nearly the same place afte the slides. The water sheet of the American Fall is so thin tha it has almost no power to make a gorge. The water was onl

3 feet (0.9 meter) deep in the deepest part on the brink before the power diversions and is now only about half as deep. This fall has therefore not been able since its beginning to remove the large blocks at its base or to bore through the Clinton strata on which they rest. The capping hard layer is not effectively undermined, and the overhang is small. This is seen in the Cave of the Winds.

It is also worthy of note that there is no deep channel in the rapids above the American Fall. The recent rock slides occurred in a part of the brink that lies close in front of Robinson Island, as shown in Figure 11. The break was not like the fall of Table Rock on the Canadian side in 1846 and 1850, a sheer drop of an overhanging ledge. It was a slide on two planes forming an angle of about 120° and dipping toward the gorge. The loosened mass separated from the gorge wall on joint planes that occur in a regular system, as shown in Figure 11. So long as the capping layer remained intact in the whole region around the falls, there was no differential effect and no tendency for the shale at this place to give way. But when the joints opened up, even in a small degree, and became channels for percolating waters, the block lost the cohesive support of the rock wall, its weight was localized, the shale under it began to yield, and the block slid down on the new fracture planes into the gorge.

The cliffs of the Upper Great Gorge have all receded a moderate amount under the action of subaerial weathering. The fact that the crest line of the American Fall is an almost perfect continuation of the cliff line as seen north of the fall and on Goat Island leaves little reason to suppose that the fall is doing gorge making at a measurable rate. The recess made by the recent rock slides is no greater than that which may be seen on the east side of the gorge about 750 feet (229 meters) north of the International Bridge, and it appears to be bounded by joint planes in the same system as those seen at the American Fall.

HORSESHOE FALL

The main mass of water, comprising over 95 per cent of the whole river, passes over the Horseshoe Fall. Since its separation from the American Fall, some 600 or 700 years ago, the main fall has gone on making the gorge as if the American Fall did not exist. Its volume is so great and the turmoil of waters in the cauldron beneath the fall is so powerful that the wall of shale rock is slowly worn away, leaving the hard capping layer overhanging. Gradually the joint planes in the limestone are opened up by percolating waters, and the loosened blocks fall off into the cauldron below. Here they are spun around in the

violent currents and become efficient tools for wearing away the shale and lengthening the gorge.

So long as the cataract was north of the col the river flowed quietly over the gravel of Goat Island and over the present site of the falls and the rapids. But as the falls retreated down the rock slope south of the col, it began cutting into the rear side of the Niagara Falls moraine and made the great bight in the drift now seen in Queen Victoria Park on the Canadian side. The rear margin of the moraine evidently extended across the present site of the rapids and the Horseshoe Fall on a curve roughly parallel with the front of the moraine in the same interval. As recession proceeded, the curved course of the river in the rapids threw a powerful current on a new curve and at a slightly higher level against the bank west and south of the fall. The bank was heavily cut away, leaving a bluff 150 feet (46 meters) high at Falls View station. This bight was cut through the crest of the moraine a short distance south of the station, so that the surface there slopes downward to the west from the edge of the bluff. Another later, smaller cut is seen at the Dufferin Islands. This was probably caused by the rock ledge of the upper cascade, which comes to the shore about at the south side of this bight.

The changing configuration of the crest line of the Horseshoe Fall has been the object of much careful investigation. On his map of the recession of this fall Spencer (73, p. 19) shows three conjectural positions of the crest line based on observations made before James Hall's survey of 1842—in 1678, 1764, and 1819. They are not accurate but are of considerable interest. The first two are wide, open curves; the third is irregular and shows a deep, sharp recess on the east side of the crest.

If the conditions of recession for the Horseshoe Fall were to continue in the future the same as they have been for the last 600 or 800 years it would take more than 1,000 years for the fall to cut the gorge back to the place of the Upper Cascade ledge, slightly more than half a mile (0.8 kilometer). But from the crest of the fall back to this ledge the rock surface ascends nearly 50 feet (15 meters). This increased thickness of the hard rock would, of course, cause a further large increase in the time required. Moreover, Gull Island, which marks the place of a wide shoal in the rapids, seems destined to divide the river into two streams, which would make two smaller gorges with an island between them, and this would still further slow up the rate of recession. Also, as soon as the amount of water diverted for power, canals, etc., is a trifle more than doubled, the American Fall will go dry. It seems certain that the river will not be allowed for long to take its natural course of recession; it will be

controlled by man. But whatever the course of future developments may be, some way ought to be found to preserve the scenic beauty of the great cararacts.

STRATIGRAPHY OF NIAGARA GORGE

At its head at Buffalo the Niagara River flows through a shallow passage in the Onondaga limestone, of Devonian age. Thence northward the entire river course to Lake Ontario is over Silurian formations. From a point near Buffalo to the upper rapids at Niagara Falls the rocks are mostly soft shales of the Salina formation and are effectively concealed by surficial deposits. The Niagara Gorge section includes the formations from the greater part of the Lockport dolomite to the upper part of the Queenston shale. (See fig. 12.) Most of the Niagara Gorge section can best be examined along the lines of the New York Central Railway and the Grand Gorge trolley line. The section is summarized below.

Niagaran series:

- Lockport dolomite. Thickness as exposed 130 feet (40 meters). This thickness includes some beds at the rapids containing Guelph fossils.
- Clinton beds. Subdivided into (1) Rochester shale, 68 feet (21 meters), carrying *Stephanocrinus angulatus*, *Caryocrinus ornatus*, *Spirifer niagarensis*, *Whitfieldella nitida* var. *oblata*, *Dalmanella elegantula*, *Spirifer radiatus*, *Diaphorostoma niagarense*, and abundant Bryozoa. (2) Irondequoit limestone, with bryozoan reefs here and there at top. About 10 feet (3 meters) of crystalline, thick-bedded, highly fossiliferous pinkish limestone. Fossils essentially those of the Rochester shale. Has zone of stylolites. (3) Reynales limestone, represented by thin magnesian limestones with *Anoplotheca plicatula* and rarely *Hyattidina congesta*. *Pentamerus oblongus*, very common in the Rochester region, is also very rare here. In the Niagara Gorge the Irondequoit and Reynales limestones are separated by a disconformity. (4) Clinton shale, green to gray shales about 5 feet (1.5 meters) thick, provisionally correlated with the Maplewood of the Rochester section. They carry the brachiopods *Anoplotheca* (*Coelospira*) *hemispherica* and *A. plicatula*. (5) Thorold sandstone, a massive quartzose whitish cross-bedded sandstone ("gray band" of authors), 8 to 10 feet (2.4 to 3.5 meters) thick.

Medinan series:

- Albion beds. These include at the top the Grimsby sandstone, about 50 feet (15 meters) thick, consisting of alternating cross-bedded red and green-gray sandstones and shales, with *Arthrophycus alleghaniensis* and *Lingula cuneata*. At least one zone (not continuous) of storm-rolled mud balls is shown. The Cabot Head shale next below is represented by only 3 or 4 feet (0.9 to 1.2 meters) of gray shale. The Manitoulin beds beneath consist of about 30 feet (9.1 meters) of dark-greenish shales with some thin-bedded argillaceous magnesian limestone carrying few fossils. The basal Whirlpool sandstone, 25 feet (7.6 meters) thick, consists of hard gray, somewhat coarse cross-bedded sandstone, mostly thick-bedded but thin-bedded in the upper 5 feet (1.5 meters). It has yielded no fossils in the gorge section.
- Queenston shales, brick-red sandy shales, exposed for 115 feet (35 meters). No fossils have been found in these beds, but in Ontario fossils occur in equivalent strata.

ITINERARY

Features near the falls on the American side.—Entering Prospect Park at the soldiers' monument, the visitor crosses several step-like terraces. These are the gravel deposits described above, laid down when the falls were at or beyond the col near Hubbard Point. At Prospect Point (north end of the American Fall) fine views of the gorge are obtained. The view south along the crest line of the fall and the cliff at the west end of Goat Island shows how perfectly the cliff continues the crest line. On crossing to Goat Island, the shallowness of the rapids above the American Fall and the absence of a deep channel are notable. Farther west along the north side of the island, at Stedman Bluff, the best view overlooking the American Fall is obtained. The recess made in the front of the fall by the recent rock slide is clearly seen. By descending the stairway near by and passing under Luna Fall, an impression of the magnitude of this small cataract is obtained. Porter Bluff, at the southwest corner of Goat Island, affords fine views of the gorge and of the seething water as it leaves the cauldron below the Horseshoe Fall; also a good view of the heavy water that pours over the central part of the fall. The Goat Island shelf in the foreground is dotted with boulders, and the water is thinner than on the American Fall. A causeway leads to Terrapin Rocks, where it is seen that the heavy water pours into the eastward recess in the crest line and over the wider south side. Passing eastward along the south side of the island, to the Three Sisters Islands, the visitor gets a view of the Upper Cascade and the ledge from which it falls at the head of the rapids.

View from the Maid of the Mist.—From Prospect Park an inclined railway leads down to the *Maid of the Mist*, a small steamer that makes a scenic excursion past the front of the American Fall and up to a position close to the base of the Horseshoe Fall. This trip affords altogether the most impressive view to be had of the great cataracts. By looking up at them amidst the spray and the roar of the falling waters, the grandeur of their height and power can be seen to the best advantage. The great blocks along the base of the American Fall are notable, especially the great pile made by the recent rock slides. A similar line of blocks fringes the base of the Goat Island shelf. The little steamer sinks a foot or more deeper than usual in the frothy water where she turns back.

Views of the falls from the Canadian side.—From Prospect Park the visitor may walk or take the electric car across the International Bridge, from which fine views of the gorge, both north and south, and also of the falls in the distance are obtained.

The car going south at the west end of the bridge affords excellent views of the American Fall from the west side of the gorge. At Table Rock House a wonderful close-in view of the Horseshoe Fall is obtained from the parapet along the west side. Farther south and east are good views of the rapids, of the great bluff west and south of the rapids, of the Dufferin Islands, and of the quietly flowing river above the rapids. The Welland River enters the Niagara River at the village of Chippewa.

Views of the gorge from the Canadian side.—After returning to the west end of the bridge, the trip is continued on the electric car northward along the top of the gorge on the Canadian side. Good views of the exposed strata in the gorge wall on the opposite side are obtained from the car all along, but especially toward Lewiston, where much of the talus has been removed by two railroad lines.

Approaching Hubbard Point, the car ascends to a higher level and passes near the place of the col, 500 to 1,000 feet (152 to 305 meters) beyond. The wide, deep gorge with quiet water extending nearly to the Cantilever Bridge and the abrupt change to a narrow, shallow gorge where the railroad bridges cross are worthy of note. For half a mile (0.8 kilometer) north of the bridges glimpses are seen of the turbulent waters of the Whirlpool Rapids. Across the river and back from the cliff a low bank of drift marks the old bank of the river when the falls were farther north. The abrupt widening at the end of the gorge on entering Eddy Basin is well marked. There is a fine view across this basin and the Whirlpool, with short rapids crossing the reef between. The momentum carries swift turbulent water along the east side of Eddy Basin, while a deep, quiet return current moves upstream on the west side.

At Sinclair Point good views to the north are obtained over the Whirlpool and its outlet, also to the east over Eddy Basin and into the lower end of the Whirlpool Rapids. The best view of the Whirlpool is from the center of the west side, looking directly down the outlet. The main current shoots north past the outlet, strikes the bank on the north side, and turns to the west and south before diving under the entering current to boil up vigorously in the outlet.

Below the Whirlpool deep, quiet water extends to the head of Foster Rapids. Wintergreen Terrace is the old floor of the river when the falls were at its eastern edge. Foster Flats and Niagara Glen mark the site of the cararact when it did not bore so deeply as in the deeper parts above, because glacial Lake Iroquois was then backed up to its highest level in the gorge. This accounts for the shallowness in this section. The

buildings of Niagara University are seen across the gorge at the bend. The gorge to the north is very even in top width, and the talus slopes are wider than the average, owing to deeper exposure of the Queenston shale and longer time for weathering.

From the bluff at the Brock monument there is a good view over the lower reach of the river and the Ontario plain. Lewiston and the area scoured by early work of the falls appear in the foreground on the east side. The wave-cut mark of the Lake Iroquois beach is seen at the foot of the hill south of Queenston. On the river bank at Queenston and on the suspension bridge can be obtained good views of the cross section of the Whirlpool sandstone that formed the terrace on which the falls fell at their beginning. The surface of the scoured area carries many large blocks and boulders. A fine view up the gorge is also obtained from the bridge.

Return trip on American side.—The return trip is made for most of the way below the cliff, near the edge of the water, and affords a fine chance to observe the behavior of the water in the rapids and in the quieter pools where the gorge is wide and deep. The river shows soundings of 150 to 183 feet (46 to 56 meters) north of the bridge, but is shallower and narrower, with some turbulence of water, up to the university. It is wider beyond, with shallow rapids up to the Foster Rapids. The gorge has a great top width over Foster Flats. The Foster Rapids are very turbulent, especially near the head, where the bottom of the Whirlpool sandstone is at the water surface. Deep, quiet water extends from the rapids to the outlet of the Whirlpool, with short rapids on the outlet reef. The Whirlpool sandstone is slightly above water at the outlet. The high bank on the northwest side consists of drift filling the St. David gorge. Another short rapids occurs on the reef at the inlet of the Whirlpool. The swift current through the east side of Eddy Basin comes out of the gorge at the Whirlpool Rapids; there is deep water in the return current on the west side.

This route affords a splendid view of the wildly turbulent water in the Whirlpool Rapids. The narrow, shallow river descends about 50 feet (15 meters) to the Whirlpool; the velocity is 22 miles (35 kilometers) an hour; the depth is estimated at about 35 feet (10.7 meters). On the east side north of the bridges the gorge wall is vertical; the top width is 750 feet (229 meters), and the width at the water surface 350 feet (107 meters). A continuous rock wall is visible under the steel arch bridge; only the capping hard limestone under the Cantilever Bridge. This is the site of the northern part of the buried Cantilever Gorge.

The electric railroad ascends the gorge wall, affording interesting rock cuts near the bridges—in limestone, sandstone, and shale (Clinton) and toward the top in the Lockport limestone, which is well exposed. The road reaches the top of the gorge opposite Swift Drift Point, enters the city of Niagara Falls on a level above the gravel deposits, and crosses the level of Lake Tonawanda shore line about 1,300 feet (396 meters) north of the railroad station. The shore line is seen in best form in the eastern part of the city about three blocks east of the high school.

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NIAGARA FALLS TO ROCHESTER

By C. A. Hartnagel

LOWER NIAGARA RIVER

From Niagara Falls to Fort Niagara, at the mouth of the Niagara River, on Lake Ontario, the route is close to the river nearly all of the way. Just before reaching Lewiston the road descends the escarpment over the Lockport and Rochester formations. The town on the opposite side of the river is Queenston, the type locality of the Queenston shale, the lower member of the Medinan. The red shales of the Queenston are seen along the bank of the river on the way to Fort Niagara. At Lewiston the basin of glacial Lake Iroquois is entered, the old shore line of which is parallel to and about 4 miles (6.4 kilometers) south of the present shore of Lake Ontario. At Lewiston the crest of the Lake Iroquois beach is 129 feet (39.3 meters) higher than the surface of Lake Ontario, which is 246 feet (75 meters) above

sea level. As a result of postglacial tilting the Iroquois beach rises to the east in this vicinity, at a rate of a little more than 1 foot to the mile (0.2 meter to the kilometer).

Near the end of the glacial period an arm of the ocean, the Champlain Sea, occupied the Ontario Basin but at a much lower level. The present lake was established by an uplift of the basin near its east end.

The site of Fort Niagara was first occupied by LaSalle as a "habitation" in 1669. In 1679 he built a small blockhouse or fort, called Fort Conti. The early structures were burned or destroyed. The first permanent fort was completed by the French in 1727 and is known as the Old Castle. Of the seven stone buildings still standing within the ramparts, six antedate the Revolution (1776). The hot-shot furnace for heating cannon balls was built by the United States Government about 1810.

From Fort Niagara the route leads southeastward through Ransomville over the bed of glacial Lake Iroquois and through an important fruit-raising district. Near North Ridge the highway reaches the beach of the glacial lake and follows it in an easterly direction, through Warrens Corner. This level, straight stretch of beach is known as the Ridge Road. In Niagara County the Iroquois beach is the "little" ridge; the "big" or "mountain" ridge is the Niagara escarpment, which can be seen south of the Ridge Road. In the vicinity of Warrens Corner the beach becomes involved with wave-washed morainic material; beyond is the valley of Eighteenmile Creek. Here was a southward-projecting arm of Lake Iroquois and also one of the outlets of a higher glacial lake known as Lake Tonawanda. The Iroquois beach again appears at Wrights Corners, where a right turn is made leading south to Lockport over formations ranging from the Queenston shale to the Lockport dolomite. The contact of the dolomite with the underlying Gasport limestone is well shown above the bridge and locks of the Barge Canal. The fauna of the Lockport dolomite is not abundant, and good specimens of fossils other than corals are not readily found.

MEDINA DISTRICT

From Lockport the route is along the Niagara escarpment, until a north turn is made at McNalls. Before coming to Gasport a valley is seen which served as one of the spillways of glacial Lake Tonawanda. Gasport is named from a natural gas seep found here in the canal basin. The Gasport limestone, characterized by an abundance of crinoid stems and plates, is typically exposed at the quarry east of Gasport, where large

quantities of crushed stone and furnace flux have been produced. The quarry face also includes beds of Lockport dolomite and exhibits a broad channel in the coral facies of the Lockport filled with sandy shale that has furnished a striking graptolite fauna of Lockport age (Ruedemann).

East of Gasport the route leads through the village of Middleport, a locality which has furnished excellent collections of Rochester shale fossils. After leaving Middleport the Medina sandstone district is entered and is followed for much of the way to Rochester. Medina is the type locality for the Medinan beds, and the type section is along Oak Orchard Creek, which passes through the village, where the upper members (Albion) are exposed. Among the characteristic upper Medinan fossils are *Arthrophycus alleghaniensis*, *Lingula cuneata*, *Whitfieldella oblata*, *Rhynchotrema plicata*, *Bucanella trilobata*, and *Lophospira litorea*. Several species of bryozoans, pelecypods, and cephalopods and the small ostracode *Leperditia cylindrica* are also represented. A line of quarries extends from the vicinity of Medina to Holley. The principal products of the quarries at present are curbstone and blocks for street paving. The route passes through Albion, which lends its name as a group term to include the various divisions of the Medinan above the Queenston shale. At Holley there is a well-marked channel or spillway that carried the glacial waters from the extreme east end of Lake Tonawanda into Lake Iroquois. At Brockport the route goes north as far as Clarkson, where an east turn is made, and for the remaining distance to Rochester the road is on the typically developed beach of Lake Iroquois. On entering Rochester the route leads across the postglacial gorge of the Genesee River, thence south through the city to the university, in the southern environs.

THE ROCHESTER REGION

By H. L. Alling and J. E. Hoffmeister

Rochester is situated on the inner lowland of New York State, 6 miles (9.6 kilometers) south of Lake Ontario. The lowland is underlain by nearly horizontal beds of Silurian age. The postglacial gorge of the Genesee River affords one of the best exposures of lower and middle Silurian formations in the State. (See fig. 12.) The preglacial channel of the river lies about 5 miles (8 kilometers) east of the gorge and is now occupied by Irondequoit Bay.

STRATIGRAPHY

The following Silurian formations are exposed in the Genesee gorge at Rochester:

- Niagaran group:
  - Lockport dolomite.
  - Clinton beds:
    - Rochester shale.
    - Irondequoit limestone.
    - Williamson shale.
    - Sodus shale.
    - Reynales limestone.
    - Furnaceville iron ore.
    - Brewer Dock limestone and shale.
    - Maplewood shale.
    - Thorold sandstone.
- Medinan group:
  - Medina (Albion) sandstone.
  - Queenston shale.

The Queenston shale, containing a few layers of massive sandstone, is exposed in the bottom of the Genesee gorge. Both sandstone and shale show numerous green blotches, the origin of which is not known. At Rochester the formation has a total thickness of about 1,000 feet (305 meters), although only the upper 60 feet (18 meters) or so is exposed. The only known trace of past life is represented by the peculiar marking known as *Paleophycus tortuosum*, which has been considered a worm burrow. The origin of the Queenston has been a matter of some controversy. The fact that its material is not at all well sorted has made some writers consider it to be a wind-blown, continental deposit. Grabau (77),[10] in support of this view, cites red color, mud cracks, and cross-bedding of an eolian character.

The Queenston has been placed at the top of the Ordovician by some stratigraphers and at the base of the Silurian by others. Ulrich (80) showed that the formation could be traced into the fossiliferous marine Richmond, which he places at the base of the Silurian. Other writers have placed the Queenston in the Ordovician and have located the Ordovician-Silurian contact at the top of the Queenston and the base of the overlying Medina. It is a difficult task to locate the Queenston-Medina contact in the gorge at Rochester. The lower formation grades up into the Medina (Albion), and there is no evidence of a major time break.

The Medina (Albion) sandstone has not been subdivided in the Rochester region, where it is a hard red massive formation about 55 feet (17 meters) thick, formerly much used for building

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[10] Numbers in parentheses refer to bibliography on p. 115.

stone. It is composed chiefly of quartz. The only traces of life in the formation in the vicinity of Rochester are the worm burrows *Arthrophycus alleghaniensis* and *Daedalus archimedes*. These burrows, the presence of numerous well-preserved ripple marks, and the cross-bedded condition of the formation point to deposition under beach conditions.

The Thorold sandstone is a gray-green sandstone about 4 feet (1.2 meters) thick. It was probably formed by a reworking of the upper part of the Medina by an advancing sea. Its only

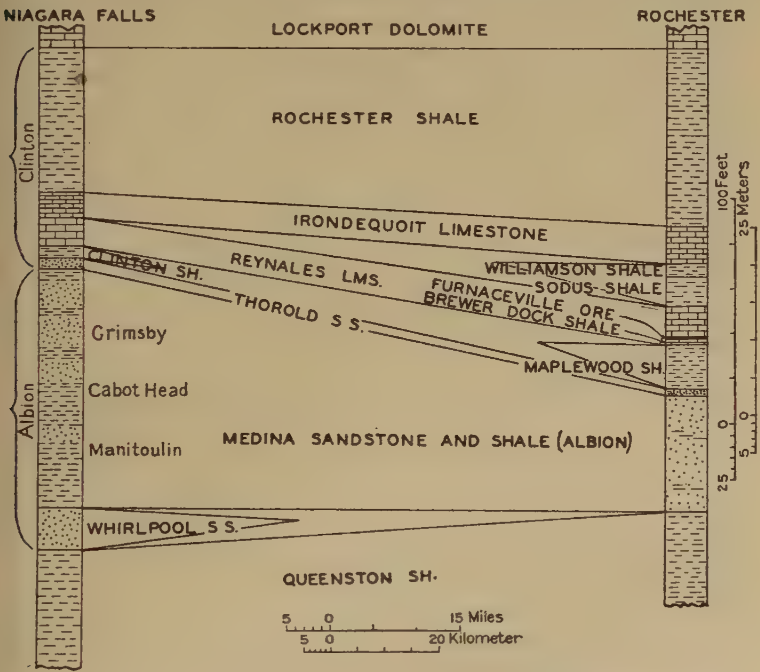

FIGURE 12.—Stratigraphic section of the Niagara Falls-Rochester area

fossil is the burrow *Arthrophycus alleghaniensis.* Ulrich and Bassler (81) place the Thorold at the base of the Clinton and consider it the initial deposit of the incoming Clinton sea. In central New York this formation becomes coarser and is there known as the Oneida conglomerate. In Oneida and Herkimer Counties the base of the Oneida marks the Ordovician-Silurian boundary.

The next youngest bed of the Clinton in the region is a well-defined green unfossiliferous shale known as the Maplewood shale.

This formation, which is 21 feet (6.4 meters) thick in the Genesee gorge, thins in both east and west directions.

Above the Maplewood occurs about 3 feet (0.9 meter) of interbedded limestone and shale, typically exposed in the Genesee gorge near Brewer Dock and locally known as the Brewer Dock limestones and shales. The characteristic fossil, found chiefly in the limestone layers, is a minute gastropod of the genus *Cyclora*. The brachiopod *Hyattidina congesta* is also found in the formation.

The Furnaceville iron ore is one of the many lenslike hematite layers which characterize the Clinton group. The most westerly exposure recorded is in the Genesee gorge, where it is about 1 foot (0.3 meter) thick. At the type locality, Furnaceville, in Wayne County, it is 22 inches (0.56 meter) thick. On the east side of Irondequoit Bay at Glen Edythe the ore is absent. The Furnaceville ore is calcareous and made up largely of fossil fragments coated with hematite. The fauna apparently is dwarfed. Bryozoans and crinoid segments are the common forms. Smythe (79) believes that the ore represents a replacement of the limestone by hematite, probably before lithification.

The Reynales limestone is composed of about 14 feet (4.3 meters) of gray crystalline limestone in which some of the upper layers are made up almost entirely of the large brachiopod *Pentamerus oblongus*. The type section for the Reynales limestone, which is characterized by the abundance of *Hyattidina congesta*, is at Reynales Basin, Niagara County. It is possible that in the Genesee gorge the Reynales may include the Brewer Dock and the Furnaceville. The upper part of the Reynales, carrying *Pentamerus*, has not been recorded from Reynales Basin. The use of the term Reynales as here employed for the Genesee gorge section is provisional.

The Sodus shale is a purple and green shale with thin layers of pearly limestone. Many of the limestone layers are composed almost entirely of shells of the brachiopod *Coelospira hemispherica*. The formation in the Genesee gorge is 14 feet (4.3 meters) thick. It increases to the east, and at Sodus, the type locality, it measures about 50 feet (15 meters).

Above the Sodus shale at Rochester lies 6 feet (1.8 meters) of black shale known as the Williamson shale. It is characterized chiefly by the graptolite *Monograptus clintonensis*, which occurs in large numbers in several thin zones. *Retiolites venosus* is another graptolite found in this shale. The Williamson, like the Sodus, thickens to the east. Between these two formations exists a hiatus which is represented to the east by the Wolcott limestone.

The Irondequoit limestone, about 20 feet (6 meters) thick, consists of interbedded layers of limestone and shale. It is very fossiliferous, and the fauna consists chiefly of brachiopods and bryozoans. The most interesting feature of this limestone is the widespread occurrence of reefs, the tops of which project into the base of the overlying Rochester shale. Many of the fossils of the Irondequoit are also common in the Rochester.

The Rochester shale is a gray calcareous shale, about 80 feet (24 meters) thick at the type locality. Its fauna is somewhat related to that of the underlying Irondequoit. An excellent exposure of the formation can be seen on Palmers Creek, Rochester, and good collections from the basal layers can be made at Densmore Creek, also within the city. The fauna of the Rochester shale is very profuse, and more than 200 species have been described from Rochester and near-by localities. A few of the fossils found in the Rochester shale are *Favosites constrictus*, *Cladopora seriata*, *Fenestella elegans*, *Dictyonema retiforme*, *Inocaulis plumulosus*, *Caryocrinus ornatus*, *Dalmanella elegantula*, *Rhipidomella hybrida*, *Plectambonites transversalis*, *Leptaena rhomboidalis*, *Spirifer niagarensis*, *S. radiatus*, *Camarotoechia neglecta*, *Pterinea emacerata*, *Diaphorostoma niagarense*, *Dawsonoceras annulatum*, *Conularia niagarensis*, *Calymene niagarensis*, *Dalmanites limulurus*, *Homalonotus delphinocephalus*, and *Lichas boltoni*.

The Lockport dolomite is a gray massive sandy dolomite that commonly contains small cavities lined with dolomite crystals. Calcite and selenite are also common, and occasionally sphalerite, galena, and fluorite are found. For the most part the formation is unfossiliferous, but in places numerous poorly preserved corals and a few brachiopods and other types are found. At Rochester it is about 80 feet (24 meters) thick.

The Rochester region is part of the worn-down coastal plain of Paleozoic beds which were deposited on the shelving surface of the ancient crystalline land mass by a sea that lay to the south. The drainage originally followed the southerly dip of the beds. In time subsequent tributary streams became intrenched on the outcrop of the shaly beds in an east-west course. One such stream flowing over the soft Queenston shales in the position of the present Lake Ontario became dominant; the Ontarian River, so called, evidently carried the waters westward to the Mississippi. Eventually by stream piracy the consequent drainage to the south was turned northward, giving rise to the Genesee River of preglacial time.

The continental ice sheet as it spread southward widened and deepened the valleys in its course and on its retreat spread a mantle of drift over the region. The most remarkable group of

drumlins in the State is to be seen a little east of Rochester. Kames and eskers are found in the Mendon Pond district, south of the city. The Pinnacle Hills, within the city limits, are kame moraines, formed apparently at the front of an ice lobe, as is pictured in the diagrams, or between two lobes, as suggested by another interpretation of the origin of these hills.

The final withdrawal of the ice caused a series of temporary lakes, of which no less than 22 have been definitely established. The directions of escape varied at different times from the south (the Susquehanna River) to the west (the Mississippi), the east (the Mohawk and Hudson), and the northeast (the St. Lawrence). The shore lines of three of these lakes are shown in the accompanying diagrams—Lake Warren (fig. 13), with a present altitude of 880 feet (268 meters); Lake Dana (fig. 14), 700 feet (213 meters); and Lake Iroquois (fig. 15), 435 feet (133 meters)—also the present drainage conditions (fig. 16).

ITINERARY

At the University of Rochester a visit will be made to the Chester Dewey Laboratories of Geology and the Museum of Natural History, where maps and models illustrative of the local geology can be seen. From the university the road leads eastward past the Rochester kame moraine to Cobb Hill. From this point a view may be had of the kame moraine, the city of Rochester, and, if clear, Lake Ontario. To the south is the clay outwash plain. From Cobb Hill the route goes to Brighton, where glacial till occurs on top of lake sands, showing evidence of the readvance of the continental ice sheet, also evidences of crumbling and minor faulting. Continuing north from Brighton the route leads to the Irondequoit Bay depression, the preglacial channel of the Genesee River, which is crossed to the east side, with a stop at Inspiration Point. Proceeding north to Lake Ontario the road crosses the spit at the mouth of Irondequoit Bay. Thence the route is to the Ridge Road, on the beach of glacial Lake Iroquois, and west to Brewer Dock, at the edge of the Genesee gorge. At this place the stratigraphic section from the Queenston shale to the middle of the Clinton beds is seen. The return is made by Driving Park Avenue to the bridge, which gives a view of the lower fall and farther south the middle fall. There is a third fall, not visible. These three falls are due to three resistant layers—from the base up the Thorold sandstone, the Reynales limestone, and the Lockport dolomite. At Maplewood Park the pavilion is on the river meander terrace, and a view is had of the postglacial gorge and the whole section from the Rochester shale down to the Queenston beds.

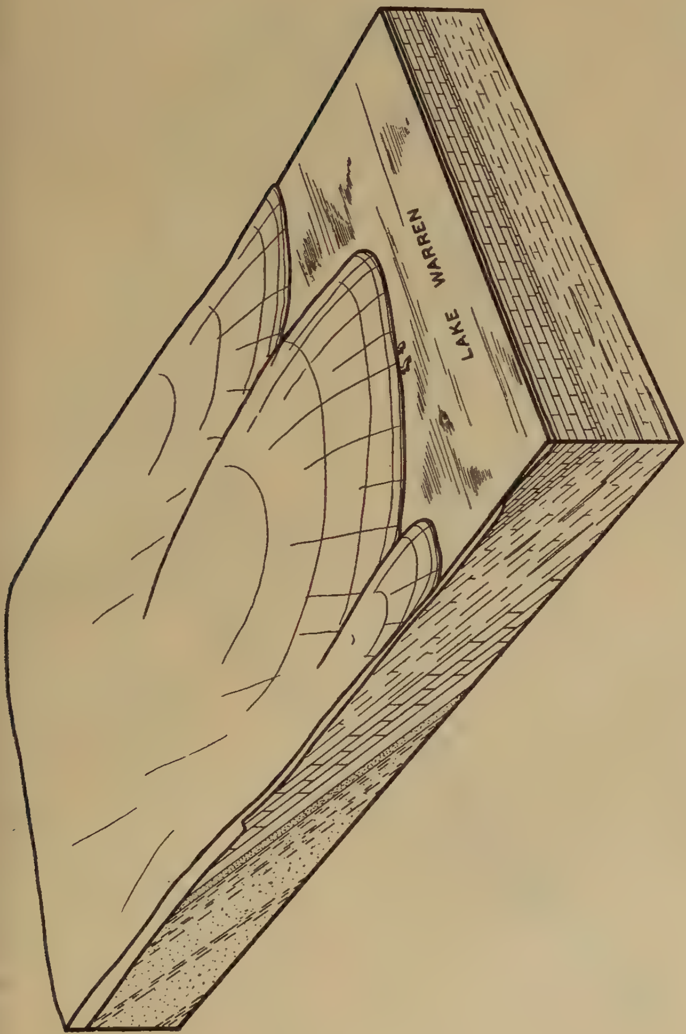

FIGURE 13.—Glacial Lake Warren. The retreating continental glacier dammed Lake Warren, which drained westward to the Mississippi. Shows formation of the Mendon kames and eskers

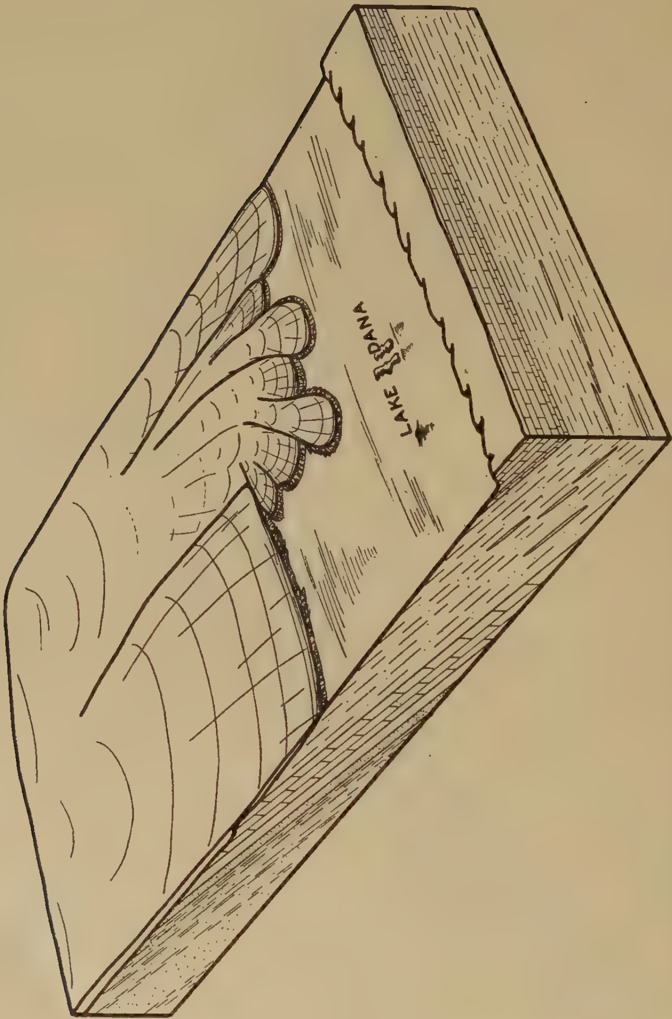

FIGURE 14.—Glacial Lake Dana and Pinnacle Hills, deposited as an interlobate kame moraine

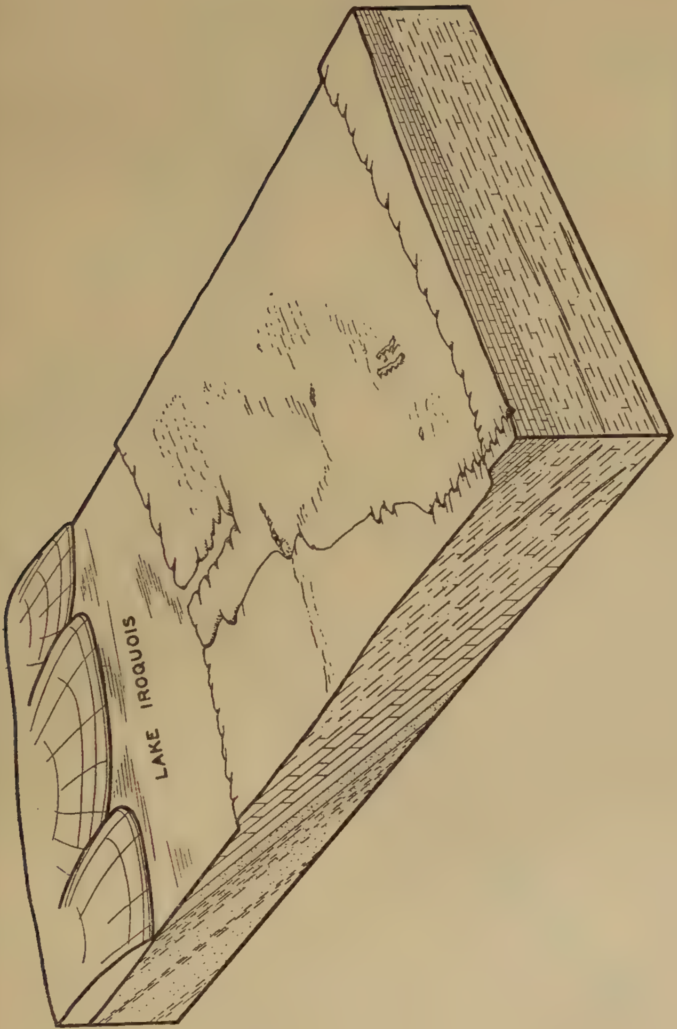

FIGURE 15.—Glacial Lake Iroquois, whose shore-line features are surmounted by the present Ridge Road

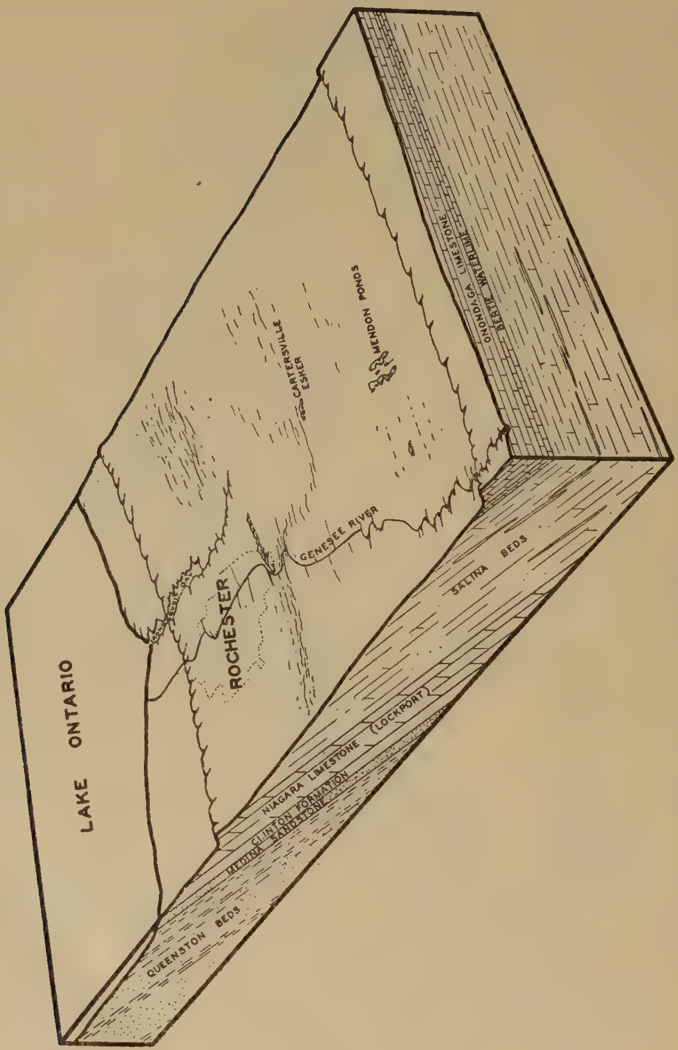

FIGURE 16.—Present drainage conditions in the vicinity of Rochester

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ROCHESTER TO UTICA

By C. A. Hartnagel

ROCHESTER TO LYONS

From Rochester the route leads southeastward to Victor, near the southern margin of the Salina formation. Near Victor a well-developed channel of ice-border drainage is seen at the right. This channel continues along the highway that leads to the gypsum mines east of Victor. Surface quarrying of gypsum was at one time carried on in the vicinity in deposits found at the top of the Camillus (Salina) shales directly below the Bertie water lime. A lower bed of gypsum 6 feet (1.8 meters) thick is now mined by Victor Plaster (Inc.), through a shaft 104 feet (32 meters) deep. Beds of gypsum are found on or near the outcrop of the Camillus formation from central New York to the western limits of the State; in depth, to the south of the outcrop, they are succeeded by anhydrite seams. The rock-salt beds of New York lie several hundred feet below the main gypsum beds, near the base of the Camillus. From the gypsum mine the route is south to East Victor and then east along the highway close to the boundary between the Salina and Onondaga limestone formations. Before Manchester is reached glacial channels are to be seen on the left, and directly northwest of Manchester is a delta deposit. At Manchester the route turns north into the great drumlin region of the State. (See fig. 17.)

Here drumlins occur singly and in groups. In some places they are so close together that their bases are fused, and there is only a shallow depression between the elongated hilltops. The drumlins were formed beneath the frontal belt of the waning ice sheet at a time when the transporting power of the ice

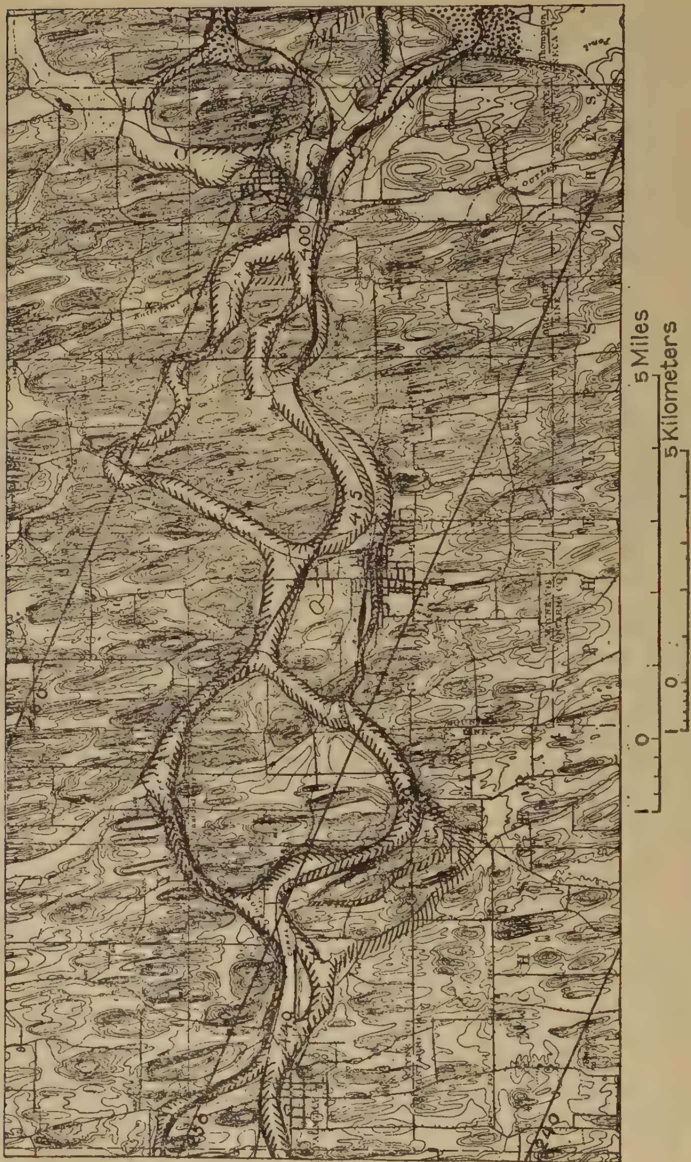

FIGURE 17.—Heart of the drumlin area between Palmyra and Lyons, showing glacial channels of ice-border drainage. Postglacial altitudes indicated by heavy black lines. (After Fairchild)

was not strong enough to push along the subglacial materials. The drumlins were built up gradually by accretion; in places along the lake shore where they have been dissected by wave action their concentric structure is plainly seen. Their longer diameters are parallel to the direction of the ice movement, and the steeper and higher ends face north, in the direction from which the ice advanced.

Among the first drumlins to be seen is Mormon Hill, 3 miles (4.8 kilometers) north of Manchester. This hill, also called Cumorah, is where Joseph Smith, the founder of the Church of the Latter-Day Saints, relates that he found the inscribed golden plates which he translated as the Book of Mormon, published in 1830.

From Mormon Hill the route leads directly north to Palmyra, where an east turn leads into a remarkable glacial stream channel in Salina shales that winds its way through the drumlin region from Fairport, a short distance east of Rochester, to Lyons, a distance of 30 miles (48 kilometers). This channel is the lowest of the glacial channels in western New York; its altitude at Palmyra, 440 feet (134 meters), is the same as the height of the beach of Lake Iroquois, farther north. The nearly level grade of this channel gives an easy route for transportation lines, and within its confines are the New York Central Railroad, the West Shore Railroad, the Barge Canal, and several highways.

At several points the channel splits but always reunites into a single one. The largest split in the channel is 3 miles (4.8 kilometers) east of Palmyra, where the New York Central Railroad follows the northern branch, and the West Shore Railroad and the highway follow the southern branch. Over most of the distance to Lyons the route leads across the long axis of the drumlins and somewhat below their bases. In some places there has been a modification of the ends of the drumlins as a result of the glacial stream which flowed between them. At Lyons the distinct glacial channel terminates, and the presence of delta deposits indicates an early stage of Lake Iroquois. At a later period the higher waters of this glacial lake occupied the channel as far west as Palmyra.

LYONS TO AUBURN

From Lyons the route, still in the drumlin area, leads south along the east side of the valley that carries the outlet of Canandaigua Lake to West Junius, which lies along the western edge of a kame deposit. From West Junius the route is southeast through Waterloo and Seneca Falls, in the Seneca River Valley, and thence northeast across the large Montezuma Marsh. This marsh lies at the foot of Cayuga Lake and represents the lake filling at its north end. Through this marsh passes the Seneca

River and a branch of the Barge Canal connecting Cayuga and Seneca Lakes. From it the road leads to Auburn over the south edge of the drumlin area. Road cuts on the way expose the Camillus shales, and near Auburn there are quarries and highway cuts in the Onondaga limestone.

AUBURN TO SYRACUSE

From Auburn the route goes directly east to Skaneateles (skin-e-at′e-lees) over the tops of several drumlins. The water seen at the right is Skaneateles Lake, 867 feet (264 meters) above sea level. The lake lies in a basin of Hamilton shales and lends its name to one of the divisions of the Hamilton formation.

From Skaneateles the road leads to Marcellus. Three miles (4.8 kilometers) from Skaneateles a deep and well-defined glacial stream channel is crossed. Marcellus lies in the valley of Ninemile Creek and is the type locality for the Marcellus shale. (See p. 34.) In proceeding down the valley a stop will be made at Marcellus (Martisco station), where a glacial stream has cut deeply into the Camillus shales, which contain specimens of hopper-shaped cavities, the external casts of salt crystals. Specimens of selenite and rock gypsum may also be obtained here. It is in this formation that the main salt beds are found, but only under a protecting cover of overlying beds. North of this locality is the village of Camillus, the type locality for the shales. At Solvay are the large works of the Solvay Process Co., manufacturer of soda products. Limestone from quarries at Jamesville and salt brine from deep wells at Tully, 17 miles (27 kilometers) away, are used in the plant. The waste material from the operations, a white sludge consisting of calcium chloride and other compounds, covers many acres in the vicinity.

Onondaga Lake, altitude 364 feet (111 meters) lies north of Solvay and Syracuse. Around the borders of this lake there existed for almost 100 years the most extensive salt industry of the country, based largely on the solar process of evaporation, making use of natural brines obtained from shallow wells. The wooden evaporating vats with their movable roofs once covered many hundreds of acres. The presence of natural brines on Onondaga Lake was first reported by the Jesuit Father Jérome Lallemant, about the middle of the seventeenth century. The source of the brine is the rock salt beds of the Salina formation to the south, and it is stored in glacial sand and gravel, the filling of a deeply buried valley. The discovery of rock salt beds in several parts of the State and the development of improved methods of artificial evaporation caused a decline in the solar salt manufacture in the district, and in 1926 operations ceased.

SYRACUSE TO JAMESVILLE

In the district southeast of Syracuse occurs a remarkable series of extinct glacial channels, cataracts, and plunge basins or cataract lakes. The series is divided into two parts by the north-south valley of Butternut Creek. Only the section west of the creek will be examined in detail.

The lowest channel is entered at the upper or west end, 540 feet (165 meters) above sea level, or 140 feet (43 meters) above the floor of Onondaga Valley, to the west. The channel is 2½ miles (4 kilometers) long east and west and forms a V-shaped gorge at the east end, where it descends abruptly into Butternut Valley. The sides of the glacial valley consist of nearly vertical walls of limestone, the Onondaga and Manlius formations, with the basal part in the Camillus shales. This channel is known as the "rock cut." Near the east end of the channel the highway curves to the south and up Butternut Valley to Jamesville. Here a right turn is made to reach the Clark Reservation, and the route leads west along a highway parallel to the channel just described. In this reservation is an extinct waterfall which in size may have rivaled Niagara. The cataract occupied a semicircular amphitheater over 1,300 feet (396 meters) in diameter. The steep limestone cliffs rise 175 feet (53 meters) above the lake. Above the cataract the remains of rock islands in the rapids are clearly shown, and the limestone beds are terraced and channeled as a result of the swift waters. Between the plunge basin and the rock cut, 1 mile (1.6 kilometers) to the north, there are several smaller rock channels with cataracts and dry plunge basins. One plunge basin has a bar built across it as a result of a slight change in the position of the falling waters. The channel above the main falls is at an altitude of 760 feet (232 meters). The cutting of a lower outlet at the north brought the cataract to an end.

JAMESVILLE TO UTICA

Returning to Jamesville the road leads by the large quarries of the Solvay Process Co., and then on to Manlius, the type locality for the Manlius limestone. North of the highway between Jamesville and Manlius there are four cataract lakes which in size and other features compare favorably with the one seen at the Clark Reservation. Some of the higher channels leading to these lakes will be noted along the highway. At Manlius the route changes to the southeast up Limestone Valley past Oran. Excellent exposures of the Marcellus shale occur along this highway. After crossing the divide into the Chittenango Valley, Cazenovia Lake, 1,190 feet (363 meters) above sea level, can be seen at the left. A singular feature of

this lake is that its outlet is at its south end, but within less than 1 mile (1.6 kilometers) the flow is northward down Chittenango Valley.

East from Cazenovia the route passes over Hamilton shales through Nelson, Morrisville, Bouckville, and Madison. Hamilton outcrops show along the roadside cuts, and the rocks here are near the type locality, which is at Hamilton, the seat of Colgate University, a short distance south of Bouckville. The southward-flowing streams seen between Nelson and Bouckville indicate that the area is in the Susquehanna drainage basin. These small streams are the headwaters of the Chenango River, which joins the Susquehanna at Binghamton. Morrisville is the most easterly location in the State where rock salt has been found.

Two miles (3.2 kilometers) beyond Madison a turn is made to the north and the Oriskany Valley is entered. At Oriskany Falls limestone quarries in the Manlius and Rondout formations are below at the right of the highway, and a quarry in the Onondaga limestone at the left. Oriskany Falls is the type section of the Oriskany sandstone, but the best exposures are not readily accessible from the main highway. The Oriskany Valley is followed to Clinton, where on the campus of Hamilton College are some good exposures of the Vernon (basal Salina) red shales. Here too are exposures of the Lockport dolomite, which thins to disappearance 15 miles (24 kilometers) southeast of Clinton. Below the Lockport the upper Clinton (Rochester) formation, here chiefly a sandstone, can also be examined. Many of the structures on the campus are built of local Clinton sandstone, and the walks are made of Vernon shale. On the east side of the valley the lower members of the Clinton, including the iron-ore beds, are seen to the best advantage. At the old mine workings fossils and samples of oolitic and fossiliferous hematite can be collected.

A short distance north of the iron mines is an outcrop of the Oneida conglomerate, which lies below the Clinton formation, at the base of the Silurian system in this part of the State. No further stops are made on the way to New Hartford and into the city of Utica.

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UTICA TO ALBANY

By Rudolf Ruedemann

Utica is the type locality of the Utica shale (Ordovician), about 700 feet (213 meters) thick. The two creeks that supplied the earlier geologists, notably Vanuxem, with outcrops are now buried in sewers in the city and inaccessible. The writer (108) [11] found that only the last of the three divisions of the Utica formation is exposed here, the others cropping out only along the Mohawk River below Utica. (See fig. 18.)

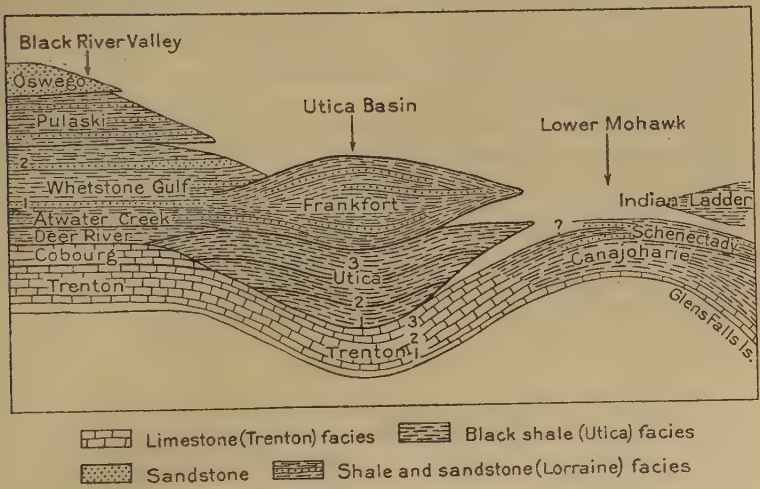


Figure 18.—Diagram of the Cincinnatian in New York

UTICA TO TRENTON FALLS

From Utica the route passes north across the Mohawk River and through the broad Mohawk Valley, which was here the bottom of a late glacial lake held by the waning ice sheet. The preglacial drainage ("Rome River") went west in this region but was reversed during the glacial period by the Iro-Mohawk River, which carried the outflow of the large Lake Iroquois. The road leads north up Marcy Hill, where much weathered Frankfort (lowest Lorraine) shale is seen in a road cut. From the top a wide view is had—to the south over the Mohawk Valley to the Helderberg erosion plain with Hamilton hills in the background; to the north across the valley of West Canada Creek to the Adirondacks.

[11] Numbers in parentheses refer to bibliography, pp. 135–136.

At the north foot of Deerfield Ridge, at South Trenton, an outcrop of the upper Utica shale is seen in the bottom of Nine-mile Creek. It contains *Climacograptus typicalis*, *Glossograptus quadrimucronatus*, *Leptobolus insignis*, *Triarthrus eatoni* (*becki* of authors), etc. Although this shale belongs to the upper third of the Utica, it is seen resting on Trenton limestone at Holland Patent, 4 miles (6.4 kilometers) farther down the creek, where the lower two Utica divisions are lacking through nondeposition.

About 1½ miles (2.4 kilometers) north of South Trenton, in a drainage ditch in a glacial valley, the Trenton is well exposed. The beds (thin-bedded blue limestone with shaly partings) belong to the uppermost division of the Trenton limestone, here underlying the Utica shale—namely, the beds with *Rafinesquina deltoidea* (Lower Cobourg, formerly Picton limestone). The beds are very fossiliferous, and besides the index fossil *Dalmanella rogata*, other forms like *Plectambonites sericeus*, *Rafinesquina alternata*, *Calymene senaria*, and *Isotelus gigas* are common. The formation is here about 100 feet (30 meters) thick, of which about 20 feet (6 meters) is exposed in the ditch.

North of the drainage ditch the road passes over a distinct glacial lake bed, the Amsterdam Lake of Fairchild (94), to Barneveld (formerly Trenton). On the left beyond Trenton Falls are the heavy delta and kame deposits of the glacial period.

TRENTON FALLS

The Trenton Falls, the type locality of the Trenton limestone, owe their origin to the fact that the preglacial West Canada Creek, which then flowed southwestward, was diverted by glacial deposits and by ice into a new course toward the southeast below Prospect. The Trenton limestone, here nearly 300 feet (91 meters) thick, consists of the following zones from bottom to top:

1. Of the lowest two zones, the *Cryptolithus* and *Parastrophia* beds, 75 feet (23 meters) thick (Glens Falls limestone), only the top beds of the upper zone are shown at the bottom of the section in the creek, where the characteristic trilobite *Cryptolithus tessellatus* may be found. These beds will be seen in other places.
2. *Triplecia extans* beds (Rockland formation), 55 feet (16.8 meters). This formation consists of thick and thin beds in the upper part, containing *Diplograptus amplexicaulis*, and thin-bedded dark limestone in the lower part. In Ottawa and Ontario another formation, the crinoid bed (Hull formation), is found between the *Prasopora* and *Triplecia* zones. It has not yet been recognized in the Trenton gorge, but may be present.
3. *Prasopora* beds (Trenton s. s.), 100 feet (30 meters) thick. This is composed of thin-bedded blue limestone with thick shaly partings. The large hemisphere bryozoan *Prasopora simulatrix* is the index fossil. Seen at power house.
4. *Rafinesquina deltoidea* (Lower Cobourg) limestone, 118 feet (36 meters) thick. (See above.) Seen at High Falls.

The uppermost division of the Trenton (Upper Cobourg formation), containing besides *Rafinesquina deltoidea* the large gastropods *Fusispira* and *Hormotoma*, appears farther north in the Black River Valley.

The locality where Walcott made his famous collection of *Calymene* with appendages was partly in a little ravine to the east of the gorge and partly on the bank of the river. The material of *Triarthrus eatoni* (*becki* of authors) with the legs and antennae described by Beecher and Raymond was obtained in the Sixmile Creek ravine near Rome, about 10 miles (16 kilometers) west of Trenton Falls, in beds at that time considered to be of Utica age but now known to belong to the Frankfort. Special notice should be given to the much discussed contorted limestone beds in the gorge, best visible below the dam. (See pl. 7, *B*.) This folding has been explained as due to expansion by crystallization (115); to the weight of the overlying strata (116); to differential movement within the limestone; to lateral pressure from the Prospect thrust fault, affecting the weaker beds (101); and to submarine slumping and gliding (95).

TRENTON FALLS TO LITTLE FALLS

From Trenton Falls the route goes southeast down the West Canada Creek Valley. The preglacial West Canada creek continued southwest in its course below Prospect (north of Trenton Falls) but was turned eastward by glacial deposits. The valley sides, especially to the north, exhibit typical kame topography and sand dunes. The well-known section of Rathbone Creek, where the lowest Trenton beds as well as the Amsterdam limestone and Lowville limestone are exposed, is passed halfway between the villages of Poland and Newport. A new exposure has been afforded by the quarry at Newport. Here a section from the Little Falls dolomite (formerly Calciferous limestone), the topmost formation of the Ozarkian system of Ulrich, is exposed at the base for about 3 feet (0.9 meter), showing typical dolomitic limestone, weathering sandy on the surface; above this 30 feet (9 meters) of light-gray pure Lowville limestone, and 5 to 8 feet (1.5 to 2.4 meters) of black Amsterdam limestone (Black River group), thick bedded where fresh and blocky in the upper part where weathered. The Lowville limestone is characterized by the vertical tubes *Phytopsis tubulosum* and the tabulate coral *Tetradium cellulosum*; the Amsterdam limestone by *Hormoceras tenuifilum* and other cephalopods (*Gonioceras*) occurring in the Watertown and Leray limestones of northern New York.

Leaving Newport and proceeding down the West Canada Creek Valley, the route passes outcrops of Little Falls dolomite

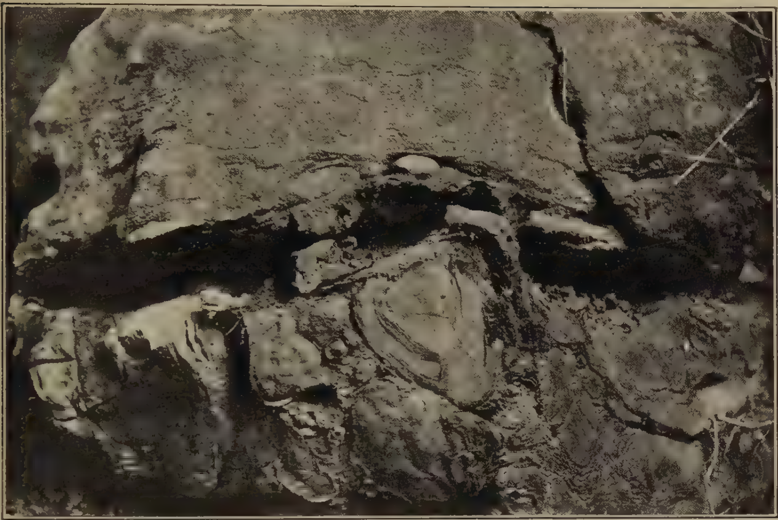
in road cuts. Just before Middleville is reached rounded masses of syenite are seen along the river bank on the right. These mark the Middleville inlier of syenite from the Adirondack massif in the Little Falls dolomite, seen at the left. Just beyond Middleville a quarry is passed on the left which gives a fine section through the Lowville to the Lower Trenton. This section shows 18 feet (5.5 meters) of Lowville limestone, followed by 6 inches (15 centimeters) of Trenton limestone with *Orthis tricenaria.* Above this is less than 1 inch (2.5 centimeters) of metabentonite, a decomposed volcanic ash (97). On top is exposed 23 feet (7 meters) of the lower Trenton. The brachiopod *Parastrophia hemiplicata*, as well as the trilobites *Ceraurus pleurexanthemus* and *Bumastus billingsi* and the large brachiopods *Platystrophia lynx* and *Dinorthis pectinella* occur here; also the ubiquitous *Dalmanella rogata* and *Plectambonites sericeus.*

From Middleville the road passes over a wide plateau, composed mostly of Canajoharie (Trenton) black shale and Utica shale. Just before Little Falls is reached a quarry in the lowest Trenton limestone is passed on the left. In Little Falls an inlier of Adirondack syenite appears in the river banks, the core of a tilted fault block. It formed a col which was the watershed in preglacial time between the eastward-flowing Mohawk and the westward-flowing "Rome River." The Iro-Mohawk (glacial drainage of the upper lakes) broke through this divide. The depositional contact of the syenite and Little Falls dolomite is seen in the cut of the West Shore Railroad just east of the station. On the south side of the valley the best exposure known of Little Falls dolomite is seen in a cliff, with 450 feet (137 meters), the full thickness of the formation, exposed in the hillside. There, in a dark layer halfway up, dolomite and quartz crystals ("Little Falls diamonds" of commerce) may be found. Fossils are rare (cephalopods).

LITTLE FALLS TO GLOVERSVILLE

Leaving Little Falls the road passes between the reddish syenite cliffs on the left and the river, with a view of Moss Island, on the right, also composed of much jointed syenite. Large potholes are visible in the cliffs on both sides, especially on Moss Island above the river level.

A mile (1.6 kilometers) below Little Falls the syenite cliffs suddenly cease. Here the main branch of the Little Falls fault is passed. The hills are now composed of Utica shale, and the Mohawk Valley widens abruptly in the softer rocks. On the south side distinct terraces are seen on the valley slopes, mostly from the Iro-Mohawk waters.



A. DISCONFORMABLE CONTACT OF THE MANLIUS LIMESTONE (WITH STROMATOPORA) AND ONONDAGA LIMESTONE AT TUNNEL CREEK, UNION SPRINGS

The horizon of the Oriskany sandstone is indicated by the dark zone in the picture. Photograph by G. D. Harris.

B. INTRAFORMATIONAL CONTORTED LIMESTONE AT UPPER FALLS, TRENTON FALLS

At the East Canada Creek bridge a detour is made up the creek for half a mile to see the Manheim fault. The fault is exposed opposite the power house and in the bank just below the power house. The Little Falls dolomite occurs on the north side; on the south side with a strong fault drag appears black shale with thin interbedded limestone bands. This transitional zone of about 100 feet (30 meters) between the Trenton and the Utica is the uppermost member of the Canajoharie shale, which is of Trenton age. Although the Trenton limestone is nearly 300 feet (91 meters) thick at Trenton Falls, it dwindles eastward to 17 feet (5.2 meters) at Canajoharie, whereas the supposed Utica shale increases to 1,000 feet (305 meters) in the lower Mohawk Valley. The writer (107) has shown by the fauna of the shales (*Corynoides calicularis*, *Climacograptus spiniferus*, etc.) that this Canajoharie shale is of lower and middle Trenton age. The Trenton limestone is hence gradually replaced by shale to the eastward. (See fig. 19.)

At the Manheim fault there is also a small dike of alnoite about 8 to 10 inches (20 to 23 centimeters) thick, characterized by the mineral melilite. The fault breccia contains some galena and pyrite, which have attracted prospectors.

From St. Johnsville eastward Little Falls dolomite is again seen in the road cuts; from Nelliston to Palatine Bridge, however, a new formation, the Tribes Hill limestone, becomes prominent along the road in outcrops, quarries, and characteristic blocks in the stone fences. An especially good outcrop occurs 1 mile (1.6 kilometers) west of Palatine Bridge. This formation, the "Fucoidal layers" of the "Calciferous" of the earlier writers, is considered the basal formation of the Canadian system in this region. It is missing farther west between the Little Falls dolomite and the Lowville limestone. Its most common fossils are the flat, closely coiled gastropod *Ophileta complanata* and a small cephalopod (*Orthoceras primigenium*); more rarely (88) (89) are found *Pleurotomaria hunterensis*, *Eccyliomphalus multiseptarius*, *Dalmanella wemplei*, *Bathyurus ellipticus*, and *Harrisia parabola*. The thickness of the Tribes Hill limestone is 15 to 40 feet (4.6 to 12.2 meters).

Beyond Palatine Bridge the road again enters the Little Falls dolomite, which continues in high cliffs on both sides to a point near Yosts, where, beyond the Montgomery County home, an inlier of pre-Cambrian rocks appears along the road (on the left) as the nucleus of another large fault block. This rock is Grenville gneiss and schist. Just beyond this point the Noses fault is passed, and the high erosion fault scarp can be seen stretching north and south. On the south side a beautiful postglacial terrace is a conspicuous feature.

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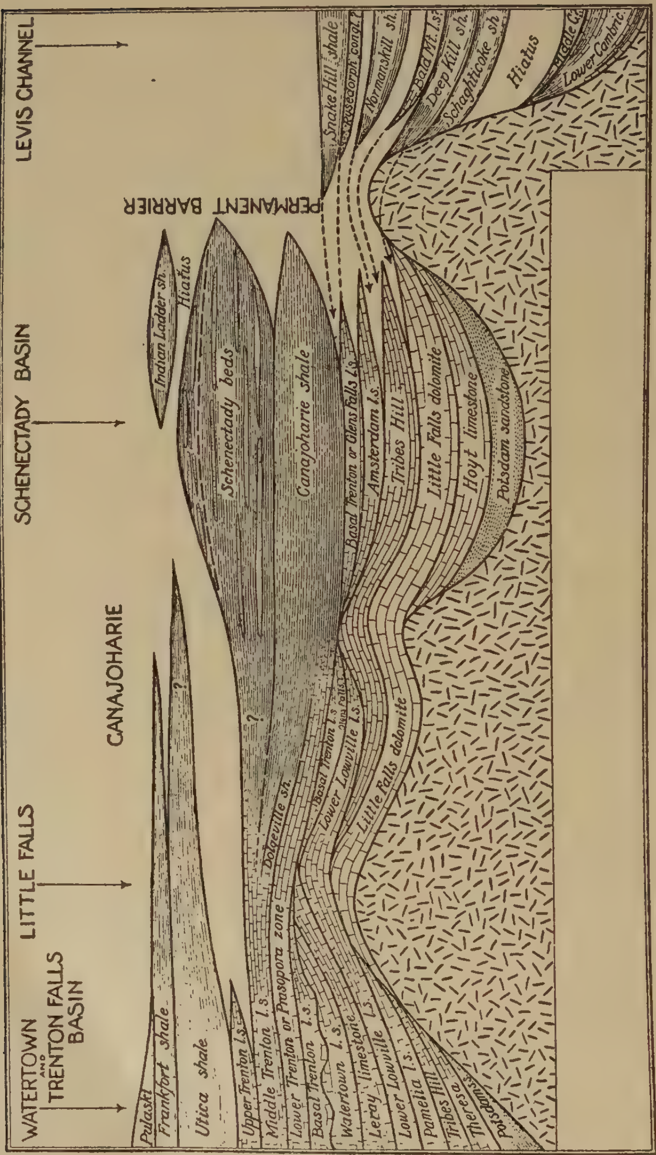

FIGURE 19.—Diagrammatic section of the Paleozoic formations in the lower Mohawk Valley. By E. O. Ulrich and Rudolf Ruedemann

East of the Noses fault the Canajoharie shale is the surface rock. It is well exposed in many road cuts between Fonda and Johnstown. From Johnstown to Gloversville the road leads through filled lake bottoms on the right and kame districts on the left.

GLOVERSVILLE TO CORINTH

Leaving Gloversville for the north the road passes over the Canajoharie Plateau. A few miles to the north the southern foothills of the Adirondacks rise about 1,000 feet (305 meters) above the road. They are composed of Grenville rocks separated from the Canajoharie shale by the continuation of the Noses fault, which has turned to a northeasterly direction. The immediate neighborhood along the road is composed of kames and old lake bottoms, and little rock is seen. Beyond Mayfield a second fault, parallel to the Noses fault, produces a graben which is entered by the road. As a result the road crosses successive strips of several formations—namely, the Trenton, not well exposed; the Little Falls dolomite near the base, well shown in a quarry 2 miles (3.2 kilometers) north of Mayfield, where about 30 feet (9 meters) is exposed with cross-bedding; the Grenville schist, in road cuts about 0.7 mile (1.1 kilometers) beyond the crusher; more Trenton limestone near Bunker Hill (with a cross fault between Trenton and Grenville); and, near an old limekiln, Little Falls dolomite and Potsdam sandstone, the latter also exposed around Sacandaga Park. To the left in the Adirondack foothills a feldspar mine (microcline) can be seen halfway up the hills, and to the right of the road is the mill where the feldspar is crushed and ground for abrasives.

The picturesque town of Northville, on the Sacandaga River, opposite Sacandaga Park, a well-known summer resort, lies in a triangular depression formed by the junction of the two faults. The high surrounding hills consist of Grenville gneiss and schist on the east and of granite porphyry and syenite on the west. To the south extends the magnificent water sheet of Sacandaga Lake.

Leaving Northville for Edinburg the road passes over outcrops of Potsdam sandstone as it ascends the hill. This formation (formerly classed as Upper Cambrian, now as Upper Ozarkian) extends around the north, east, and southeast sides of the Adirondack massif. It reaches 1,100 feet (335 meters) in thickness in the northeast but is reduced to 40 or 50 feet (12 to 15 meters) in this neighborhood. It varies in thickness with the uneven pre-Cambrian basement and begins with a basal conglomerate. Fossils are rare; the long-range brachiopod *Lingulella* (*Lingulepis*) *acuminata* occurs in a shaly layer in the basal conglomerate.

Huge sand dunes are conspicuous in the large kame region extending north of Edinburg. The kames cover the Little Falls limestone, which forms the surface rock north of Edinburg as far as a fault (parallel to the Noses fault) that separates it from the pre-Cambrian. Another large fault passes up the other side of the Sacandaga Valley, making the valley a graben.

The border of the Adirondack pre-Cambrian area is reached just west of Edinburg, but the rocks here are hidden beneath terraced glacial sands. At Edinburg the road turns northward and continues for 15 miles along the shore of Sacandaga Lake. This lake or reservoir came into existence in 1930 with the completion of the Conklingville Dam, and when filled it covers 41.7 square miles (108 square kilometers), with a capacity of about 38,000,000,000 cubic feet (1,064,000,000 cubic meters). Its principal function is to regulate the flow of the Hudson River, which is subject to marked seasonal fluctuations.

The first outcrops by the roadside, 10 miles (16 kilometers) below Edinburg, consist of Grenville schists in rather typical development. Their stratified arrangement is quite evident, although the original sediments have undergone complete recrystallization and have been subjected to igneous injection and metamorphism. No limestone is to be seen in the roadside outcrops, but limestone occurs in small bands within the series. This Grenville area covers several square miles and is separated from a similar area to the south by a laccolith of granite, which crops out along the opposite shore of the lake. The beds on both north and south sides dip away from the granite, and their strike is approximately parallel with the granite contact.

At the Conklingville Dam the Grenville schist and the granite are found in association, with clear evidence of the intrusive relations of the granite and the doming of the schists above it. The schists are cut by pegmatite and granite offshoots of the main body and to a considerable extent are infused with igneous material. The granite near the contact has a gneissic texture, well shown in the parallel arrangement of biotite and garnet, both resulting mainly from assimilation of the schists. The granite in normal development contains much smaller amounts of ferromagnesian minerals. It belongs to the main Adirondack syenite-granite series.

CORINTH TO SARATOGA SPRINGS

Below Conklingville the road follows the winding river through a gorge cut in granite (the full depth of the gorge is hidden by heavy sand deposits) to the outlet into the Hudson River at Hadley. From this point to Corinth, where the pre-Cambrian

is left behind, there is little to be seen but glacial lake beds, which are correlated by Fairchild (94) with the levels of Schoharie Lake, in the Mohawk Valley, but which may be in part the result of a local ponding of the waters by an ice lobe in the Hudson Valley below Corinth (102).

At Corinth the route returns to the Paleozoic sedimentary rocks. The Hudson River makes here a sharp turn to the northeast and breaks through the high pre-Cambrian ridge of the Luzerne Mountains, thereby becoming the source of much power at Spier Falls. Its old preglacial course was straight south through the valley followed by the excursion. Its new course may be partly interglacial (111). The bottom of the valley about Corinth is filled with deposits of the glacial Lake Corinth (87), but enormous masses of sand have been dumped by glacial waters against the sides of this valley, especially on the west, partly behind decaying ice. These glacial kames, outwash deposits, and drumlins, especially around Greenfield Center and South Greenville, effectively hide the rocks that underlie the valley, which consist of Potsdam sandstone, Theresa formation, Hoyt limestone, and Little Falls dolomite.

The new formations, not observed hitherto farther west, are the Theresa formation and Hoyt limestone. The Theresa, consisting of alternating beds of sandstone and dark limestone, is a transitional formation from the Potsdam sandstone upward. The Hoyt limestone, however, is a calcareous, very fossiliferous facies of the upper Theresa, found only in the area west of Saratoga. It consists of alternating beds of black limestone and gray dolomite and is a more off-shore phase of the Theresa. Its most characteristic fossil is the calcareous alga *Cryptozoon proliferum*, beautifully displayed at the Hoyt "*Cryptozoon* (Lester) Park." Across the road is an old limekiln and abandoned quarry, the Hoyt quarry, which has furnished a number of lower Ozarkian (formerly upper Cambrian) fossils described by Walcott, notably *Lingulella* (*Lingulepis*) *acuminata*, the primitive gastropods *Triblidium cornutiforme*, *Matherella saratogensis*, *Mathewia variabilis*, *Pelagiella hoyti*, and *P. minutissimus*, and the trilobites *Agraulos* (*Plethopeltis*) *saratogensis*, *Lonchocephalus* (*Saratogia*) *calciferus*, *Dicellocephalus* (*Tellerina*) *hartti*, *D. tribulis* and others. Many of these fossils are found in greater number and better preservation in an abandoned quarry a mile north of Saratoga Springs.

SARATOGA SPRINGS

Going eastward from the Hoyt quarry to Saratoga Springs, the road leads over the northern margin (stratified sands and clayey sands) of the great glacial Lake Albany. Saratoga

Springs is one of the most noted health and sport (racing) resorts of the United States. It owes its prominence to a series of springs that are highly carbonated and carry substantial proportions of sodium chloride and calcium, magnesium, and sodium bicarbonates, with minor amounts of bromides and iodides, but very little sulphates. This combination is possessed by very few natural waters in other parts of the world. The springs emerge on the downthrown side of a large fault, the Saratoga fault, a branch of the McGregor fault farther north, which with a throw of at least 1,400 feet (427 meters) (92) separates the pre-Cambrian and middle Ordovician. The Saratoga fault, the fault scarp of which is exposed in High Rock Spring Park, shows Little Falls dolomite with fault breccia on the west (upthrown) side. The highest bed on the east (downthrown) side (not exposed) is Canajoharie shale. The Little Falls dolomite exposed in the scarp is very near the top of the formation, and the throw of the fault is altogether not more than about 160 feet (48.8 meters) (92).

The water will be tasted at the famous Hathorn Spring. Its source has been much disputed. It was the consensus of the earlier geologists (Kemp (98) and others) that the water is of deep-seated igneous origin, a view also upheld by Colony in a recently published report. Certain objections raised against this view by Cushing (92) caused the writer to suggest that the water, notably the carbon dioxide, might be of metamorphic origin, the carbon dioxide being produced by the metamorphism of limestone into silicates, deep below the eastern mountains, whence the water seems to come. More recently Doctor Ant, the chemist of the Springs Commission, from a long study of the water, has come to the view (not yet published) that the solid ingredients of the mineral water are derived by interaction of constituents of the Canajoharie shale. The water is being stored in a large basin, extending east, north, and south in the Little Falls dolomite.

From Saratoga the route leads east over a plain, largely formed of Lake Albany deposits, mostly clays, but underlain first by Canajoharie shale, then by Snake Hill shale, and finally about Schuylerville, by Normanskill shale. The Canajoharie shale and Snake Hill shale are both of Trenton age and essentially equivalent, but although the Canajoharie rests upon lowest Trenton limestone the Snake Hill overlies Normanskill shale (of Chazy age). The two formations are members of two entirely different sets of formations and must be regarded as deposits of two different basins. (See fig. 20.) These two long basins extended, together with others, from Lower Cambrian time (or earlier) in the direction of the later Taconic and

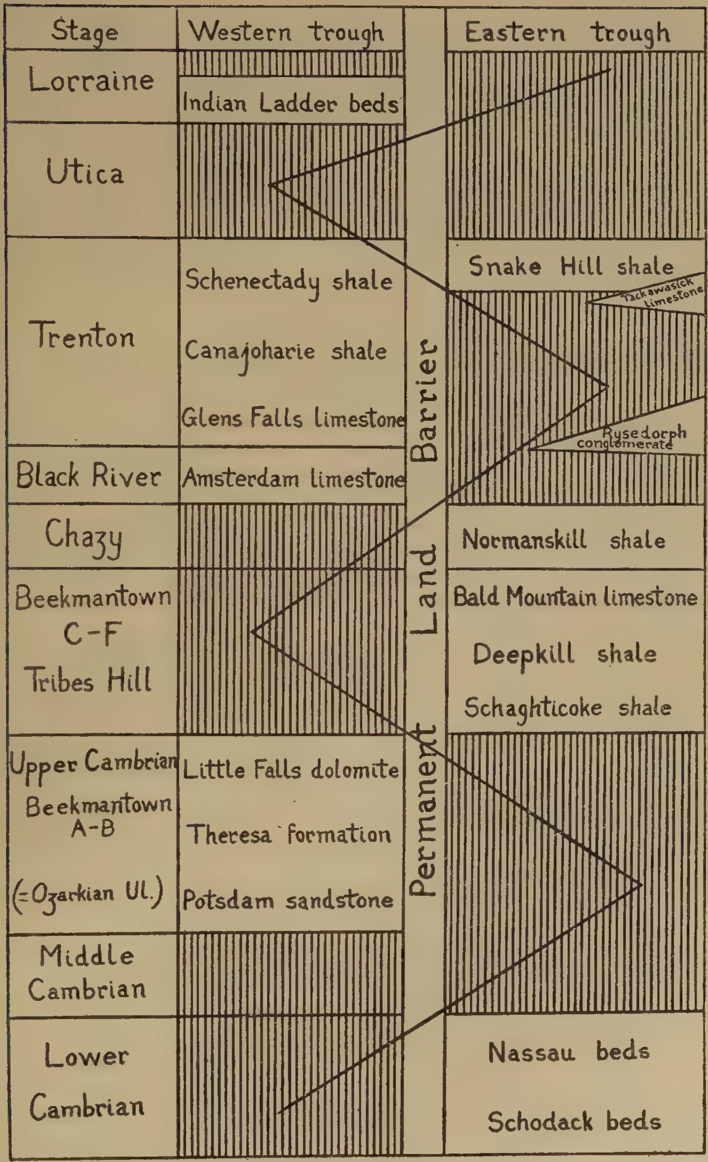

FIGURE 20.—Emergence and submergence in eastern and western troughs (109)

Appalachian folding and within the Appalachian geosyncline. The basins are known as the Levis and Chazy Basins (114). Figure 20 shows the two sets of formations deposited in the two basins and also the oscillating emergences of the two basins, as a result of which the formations in the two troughs alternate fairly regularly. The zigzag line indicates the shifting of the alternate movement from one trough to the other. The two sets of formations have been brought into contact by extensive overthrusts during the Taconic revolution, which have completely overridden the barrier that once separated the basins (109).

SCHUYLERVILLE DISTRICT

Before reaching Schuylerville, on top of the terrace, there is a view on the right of the obelisk that commemorates the surrender of Burgoyne's army in 1777 at Schuylerville (then Saratoga). Eastward is a magnificent view of the Hudson Valley, with its clay banks, and of the mountain ranges beyond. These are all parts of the Taconic-Green Mountain fold system that began to rise in the Taconic uplift (late Ordovician) and was completed in the Appalachian revolution (late Carboniferous-Permian). In clear weather both the Taconic Range in Massachusetts (southeast) and the Green Mountains in Vermont (northeast) are visible.

At Schuylerville the road turns north, following the Hudson River valley and passing the Marshall house (hospital during Saratoga siege, 1777), an inlier of Normanskill shale, with fossils, and Stark Knob, a diabase boss of unknown age and relations, locally known as the "volcano." The river banks are formed on both sides by clay cliffs about 100 feet (30 meters) high, either marine channel deposits (94), or the deposits of the glacial Lake Albany (117), or a series of marginal lakes (109) formed by a rising of the country to the south, or by ice remnants in the river valley. In the immediate neighborhood of the mouth of the Batten Kill a large delta was built into the lake by that stream (87). The road crosses the river and climbs the top of the bank, where a perfect terrace or terraces are found. It leads over this Lake Albany and Batten Kill delta terrace to the westernmost of the ridges of the Taconic fold system.

At the foot of this ridge is the Bald Mountain quarry, where the greatest overthrust of the northern Appalachian system, known as "Logan's line," is excellently exposed. This overthrust extends with possible interruptions from the lower St. Lawrence to New York State and possibly beyond. The quarry is probably the finest exposure of an overthrust plane in the East. At the base is the white, very pure Bald Mountain limestone, of

Beekmantown age (Lower Ordovician or Canadian system). The extremely jagged top of this limestone is broken into steep needles that project into the overlying black shaly mass, which is of very unequal thickness, lacking in some places and 30 feet (9 meters) thick at the east end of the quarry. This is a ground-up fault breccia (109).

Above the fault-breccia masses of olive-green grit (Bomoseen grit) and of black and green shale alternating with thin-bedded limestone (Schodack shale) are seen, more or less mixed. Both of these formations belong to the Lower Cambrian (Georgian). They compose the bulk of the whole mountain. Fossils can be found in the Cambrian on the mountain side, mostly in the limestone—the brachiopods *Obolella crassa* and *Botsfordia caelata*, the pteropod *Hyolithellus micans*, and the trilobite *Elliptocephala asaphoides*. The fault breccia contains fossils in pebbles of various ages up to Trenton. Close by are outcrops of Rysedorph conglomerate, which are very fossiliferous. A block of this rock is seen in the north end of the quarry, and another a little to the west in a cliff. The Bald Mountain limestone is rather barren in the quarry, but a few cephalopods (*Cameroceras brainerdi*, and *Cyrtoceras confertissimum*) were found. Several localities a little farther south, notably an abandoned quarry near Middleville, have furnished richer faunas especially gastropods (two undescribed species of *Eccyliopterus*, *Hormotoma cassina*, and small brachiopods).

The Rysedorph conglomerate at the north end of the quarry affords the brachiopods *Plectambonites pisum* and *Dalmanella rogata*, and the trilobites *Calymene senaria* and *Isotelus maximus*, indicating the presence of rocks of Trenton and older age. The faunas of the Rysedorph conglomerate, which are now known from Quebec to Alabama, have an Atlantic aspect with species of *Lonchodomas*, *Tretaspis*, etc., in distinction from the Pacific and Arctic aspects of the Trenton formations farther west.

Of especial significance is the southern part of the quarry, which extends eastward and gives a section at right angles to the front view of the quarry. Here the broken and overturned (rolled) Bald Mountain limestone is seen distinctly overlain by fault breccia—Bomoseen grit below and Schodack shale and limestone above. Also the fact becomes apparent that instead of one fault plane there is a zone of movement indicating a shear zone.

The Bald Mountain limestone is underlain by Snake Hill shale and therefore separated by another overthrust plane also from the Trenton formation. This plane is well exposed below the Batten Kill bridge at Middle Falls, 2 miles (3.2 kilometers)

south of Bald Mountain. It is thus apparent that a whole zone of overthrust planes (Schuppenstruktur, or shingle block) is present.

On the return trip to Schuylerville over the Lake Albany terrace the visitor should note the distant Adirondack Mountains and in front of them a distinct lower erosion plane (toward Saratoga Lake). Where the road comes down to the Batten Kill, at Clarks Mills, there is an excellent fossiliferous outcrop (graptolites) of Normanskill shale and grit. Here is seen a most distinct "shingle" structure, the shingles only 10 to 20 feet (3 to 6 meters) apart, marked by calcite veins, each with a throw of only a few inches, but producing the effect of a large overthrust, bringing the Normanskill shale (to the west) to the level and above the normally overlying Snake Hill shale (to the east).

SCHUYLERVILLE TO ALBANY

From Schuylerville southwest to Victory Mills the route leads past outcrops of Normanskill shale. Half a mile (0.8 kilometer) beyond Victory Mills outcrops of the characteristic white-weathering chert of the Normanskill formation are seen on the right and in the road cuts, just before crossing Fish Kill; on the left is a very level plain, denoting a former course of the Hudson River (117). Two miles (3.2 kilometers) beyond, the road enters a hilly region, locally known as the Rocky Tucks, with numerous close folds, the projecting vertical ledges of hard Normanskill grit causing the irregular surface. This grit is also seen in numerous road cuts on both sides of Quaker Springs. At Quaker Springs is a mineral spring with water of Saratoga type, showing that the basin extends eastward.

Two miles (3.2 kilometers) south of Quaker Springs the road enters the famous Saratoga battlefield. At the blockhouse a fine view of the mountains to the east is obtained, with the clay plateau of the Lake Albany deposits in front; the deep Hudson River Valley, eroded into that clay plateau; across the river the Cambrian-Ordovician foothills back of Logan's fault; behind them the Taconic Mountains (metamorphosed Cambrian and Ordovician rocks); and to the southeast the Rensselaer grit plateau, composed of a thick mass of barren grits and shales of unknown age (supposedly Upper Devonian).

From the battlefield the road descends to the river valley and passes over Snake Hill shale, which is everywhere exposed in the river banks as far as Mechanicville. It is a gray to black shale, at least 2,000 feet (610 meters) thick, of Trenton age, with a shale fauna, mostly graptolites. The shale is steeply folded. At Mechanicville are paper mills where a well driven to a depth

of 2,300 feet (701 meters) encountered highly mineralized water of the Saratoga type. Where the road mounts the plateau again it passes road-metal pits of black Snake Hill shale.

On the road toward Clifton Park there are more fine views of the mountains across the Hudson River. The long ridge extending east-west north of Troy is Mount Rafinesque, so named after the French scientist, an east-west cross fold in the north-south fold system. Directly north of it is Rice Mountain, the top of which consists of white-weathering Normanskill chert that through its hardness serves as backbone of many of the projecting mountains and hills. The deep ravine cut into its north slope is the valley of the Deep Kill, the type locality of the Deepkill graptolite shales (of Beekmantown age). North of Clifton Park the route enters a large sand-dune area, which continues for several miles south of the village.

Between Mechanicville and Crescent, especially south of Clifton Park, bare areas are noticeable in the pastures, where the sod has been stripped off to obtain molding sand of late Pleistocene age. The sand, which forms a layer averaging 2 feet (0.6 meter) thick, is used for the finer kinds of castings and shipped as far as the Pacific coast. The shipments of this sand amount to about 500,000 tons (453,500 metric tons) a year. The sand attains the proper degree of cohesion by the weathering of shale particles mixed with it, which produces a binding film of clay.

At Crescent the Mohawk River is crossed. On the other side of the river, where the top of the ridge is reached, outcrops of Normanskill grit appear, and beyond the river the Rensselaer grit plateau is seen to great advantage. The remainder of the trip to Albany the road passes over the terraced lake deposits.

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